The University Of Sheffield.

Holistically understanding and enhancing the adaptation of remote high-mountain communities to hydrometeorological extremes and associated geohazards in a changing climate

by

Vaibhav Kaul

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

Department of Geography
Faculty of Social Sciences
The University of Sheffield

June 2019

Abstract

In rapidly warming high-mountain environments, extreme precipitation events commonly generate extensive slope failures, flash floods and glacier-related hazards, which can be devastating to resident communities. This interdisciplinary project seeks to holistically understand human engagement with the severe risks arising from such geohazards in the wake of recent climatic change and also contemporaneous processes of social change. Focusing on remote rural communities in two monsoon-affected river basins in the Indian High Himalaya, the study uses extended ethnographic fieldwork, qualitative local-scale geomorphological observations, and quantitative hydroclimatological analyses to assess current and future environmental risks as well as local understandings and cultural models of those risks, community resilience, and adaptive capacity. The findings are synthesised to devise a strategic framework for culturally responsive action to protect and improve lives and livelihoods.

The dissertation places ontologically disparate local/traditional and Western/modern scientific understandings of climate-related geohazards into the context of each other, allowing the unique insights offered by each to be appreciated against the backdrop of the other. It uses shared geographies to integrate the seemingly irreconcilable knowledge systems, both spatially and conceptually. The practical outcome of this epistemic synthesis is that it enriches earth science-based hazard assessments with ethnographically robust emic perspectives on geomorphic processes, providing external development practitioners, planners and policymakers with a genuine sense of lived experiences of change and extremes in the physical environment.

Much of the ethnography intensively examines the fascinating dimension of indigenous geographical knowledges that transcends the materiality of the environment and the hazards that operate in it. This includes explorations of folkloristic models of landscape dynamics that lend form and spatiality to traditional metaphysical convictions, spiritualities, moralities, and emotionalities associated with geohazards operating within a certain social change context. By engaging with these commonly overlooked but behaviourally potent aspects of human-environment relationships, the epistemology of hazards developed in the dissertation can aid in developing more culturally compatible, and therefore potentially more efficacious, strategies for climate change adaptation and disaster risk reduction in remote high-mountain settings across the Himalaya and elsewhere in the Global South.

Acknowledgements

I am infinitely grateful that my doctoral project was hosted by as happy and hearty an institution as The University of Sheffield, and that it was supervised by the profoundly wise, benevolent and dedicated Dr Matthew Watson, Dr Julie Jones and Dr Darrel Swift, all of whom I have come to hold in the highest esteem. As my prime overseer, guide and teacher, Dr Watson has shown remarkable thoughtfulness, poise and magnanimity. My deepest thanks are due also to each and every one of my present and former colleagues, mentors, and friends within and beyond the Department of Geography.

This dissertation could not have been produced without the Upper Lāchen Chú and the Upper Mandākinī communities' graciousness in allowing me to explore their rich and complex worlds of experience; nor would it have come about without the exceedingly generous financial support provided by the University of Sheffield through the Vice Chancellor's Indian Scholarship (2014-2017), by the Dudley Stamp Memorial Fund and the Royal Geographical Society (with the Institute of British Geographers) through the Dudley Stamp Memorial Award (2015), and by the Department of Geography at The University of Sheffield, where I was nurtured by the Culture, Space and Difference (CSD), Ice and Climate Research at Sheffield (ICERS), and Landscape Dynamics research clusters as well as the multi-institutional White Rose Social Science Doctoral Training Centre. I am also indebted to the following institutions and programmes for the research outreach opportunities or data support they have been kind enough to provide: The University of Sheffield's Festival of the Mind, HRH The Princess Royal, the Sheffield Institute for International Development, Geography Outdoors (Royal Geographical Society with IBG), the School of Geography and the Environment at the University of Oxford, the Oxford India Centre for Sustainable Development, the Department of Geography at the University of Cambridge, the World Meteorological Organization, the British Universities and Colleges Film and Video Council's Learning on Screen Awards, the Swiss Agency for Development and Cooperation, Kumaon University, the Indian Himalayas Climate Adaptation Programme, the India Meteorological Department, and the India Habitat Centre.

Finally, I must humbly acknowledge that the vital force behind all my work is a constant supply of deep love and inspiration from nature, especially shimmering snows and cirrus-streaked skies, and from my marvellous family, clan, ancestors, elders (including my loving nanny and many adoptive Himalayan grannies), teachers (three from kindergarten, ninety-nine from four schools, thirty-three from three universities, and more than a hundred others), friends and guardian angels (at least twenty-two women, twenty men, twelve larches, nine birches, three grand cedars, three dozen sheep, three dozen swans, three children, three infants, and one foetus), philosophical companions (especially a bewitching young lady whom I have never met), creative partners, musical muses, fellow mountain lovers, saints, doctors, and deities – both gentle and fierce. I dedicate this dissertation to all of them, as also to the earnest labours of my truly good and mountain-hearted parents Vandita and Vivek, the subtle splendour of my sagacious-smiled sister Vani, and the gorgeousness of my grandparents and great-grandparents (including a gallant great-grandfather whose titanic thesis on alkaline soils was confiscated by a rather acidic British colonial government as punishment for his participation in the 1930s Indian freedom movement). May they all forgive me if I have failed them!

And thanks ever be unto my beloved Himalaya, my only home!

That reminds me of a beautiful song by James Copeland:

No land's ever claimed me,
Tho' far I did roam,
For these are my mountains,
And I have come home!

Table of Contents

List of Tables

List of Figures

1. Research context and intent

This dissertation is motivated by the enormity and immediacy of the human challenges posed by slope- and flooding-related hazards linked to extreme rainfall in rapidly warming, geomorphically unstable high-mountain environments such as the Indian Himalaya. The geophysical and social context in which the need for the study arose is outlined below. It is this context that shapes the intent of the dissertation, which in turn shapes its content.

Intense rain is capable of triggering devastating landslides, flash floods, and glacier-related hazard events such as outburst floods or debris flows from moraine-dammed glacial lakes in high-mountain environments (see, for example, Guzzetti et al. 2008, Crosta and Frattini 2001, Cannon and Gartner 2005, Caine 1980, Au 1993, Delrieu et al. 2005, Clague and Evans 2000, Clague and O'Connor 2015, Walder and Driedger 1995, Warburton and Fenn 1994, GAPHAZ 2017, Allen et al. 2016, Costa and Schustler 1988). In the regional context of the Himalaya, the June-September summer monsoon rainy season accounts for nearly all of the extreme rainfall events that induce the above hazards (see Froude and Petley 2018, Petley et al 2007, Richardson and Reynolds 2000, Krishnan et al. 2019).

Since the mid-20th century, the character of summer monsoon rainfall in the Indian subcontinent has changed such that the frequency and intensity of daily heavy rainfall has increased, and so has the contribution of short-spell high-intensity events to the total seasonal rainfall amount (Goswami et al. 2006, Dash et al. 2011). Likewise, the Himalayan region has, on the whole, seen a significant increase in extreme rainfall along with a trend towards wetter summer monsoons since the 1960s, even despite a slight regional-scale weakening of the summer monsoon over the past century (Zhan et al. 2017, Ren et al. 2017, Krishnan 2019). This has coincided with the Himalaya having warmed up at a regionally averaged rate of about 0.2°C per decade since the mid-20th century, which is roughly equivalent to the average rate of global land surface warming (Ren et al. 2017). Notably, climate warming across the Himalayan region has accelerated sharply since the 1980s, with annual mean temperatures increasing at a regionally averaged rate of 0.6°C per decade in the period 1982-2006, which is considerably higher than the global rate of land surface warming (Shrestha et al. 2012). A corresponding acceleration of rainfall intensification has been observed across the Himalayan region since the mid-1980s (Ren et al. 2017). This regional trend towards a more extreme rainfall regime in a warmer climate is projected to continue throughout the 21st century (Wu et al. 2017, Krishnan et al. 2019).

The climatic changes described above are particularly disquieting because monsoon-affected parts of the Himalaya are already the global hotspot for fatal rainfall-triggered landslides (Froude and Petley 2018, Petley 2012, Petley et al. 2010). The region is also exposed to the hazard of catastrophic rainfall-triggered outburst floods from dozens of glacial lakes, which have been expanding due to glacial recession since the end of the Little Ice Age in the mid-19th century, and particularly in response to accelerated climate warming since the 1970s (Bolch et al. 2019, Maurer et al. 2019, Richardson and Reynolds 2000, ICIMOD

2003, 2004, 2005). Not surprisingly, therefore, extreme impacts of monsoon rainfall have been recurrently reported from the region. For instance, in June 2013, several thousand people were killed and more than 110,000 had to be rescued after the Western Himalayan province of Uttarakhand in northern India was ravaged by a rainfall-induced outburst flood and debris flow from a moraine-dammed lake as well as widespread rainfall-triggered flash floods and earth slides (PTI 2013, TNN 2013, Ramachandran 2013, Dobhal et al. 2013, Singh et al. 2014, Allen et al. 2016). This was the most fatal fluvial disaster in South Asia since 1980 (EM-DAT data, cited in Bubeck et al. 2017), the deadliest and most damaging glacial flood ever recorded in Asia (Carrivick and Tweed 2016), and by far the world's deadliest landslide disaster in the period 2004-2016 (Froude and Petley 2018, see also Allen et al. 2016). The reconstruction cost for the disaster was estimated at US $661 million (JNRDA Team 2013).

In view of the extensive losses that have resulted from events such as the 2013 disaster, the high likelihood of similar situations arising in the near future, and the ongoing amplification of risk due to rapid climatic change as well as concurrent socio-economic change, remote high-mountain communities such as those in the Indian Himalaya urgently need workable strategies for risk reduction. Engineering-based mitigative interventions can play a crucial role in managing the risk associated with the kinds of geophysical hazards described above (see, for example, Reynolds 1992, 1998). However, governments in the Himalaya and similar Global South settings often lack the financial, technical, and technological resources needed to undertake sophisticated large-scale capital-intensive structural hazard mitigation projects for geographically isolated and dispersed high-mountain communities. This fundamental challenge is compounded by the inflexibility of structural interventions, both vis-à-vis local-scale environmental and cultural peculiarities as well as in relation to the complex uncertainties of climate change (Sovacool 2011, Kaul and Thornton 2014). Therefore, non-structural adaptive solutions, which involve behavioural, social, economic, and political measures, become indispensable.

In order for any environmental risk reduction measure to be successful on the ground, it needs to be responsive and relevant to the cultural context within which it operates (Bankoff 2004, Ford et al. 2016). This is because culture, through its profound influence on deep-seated beliefs, values, and attitudes, plays a central role in shaping human conceptions of, and engagements with, environmental risk, especially in traditional societies (Schipper et al. 2014, Schipper 2010, Bankoff 2004, Gaillard and Texier 2010, Crosby 2008, Schlehe 2010, Lavigne et al. 2008, Bachri et al 2015, Sherry and Curtis 2017, Bjønness 1986). Despite their behavioural potency, cultural constructions and interpretations of environmental hazards remain underappreciated in climate change and disaster research, especially from *emic* or cultural insiders' perspectives and through the lens of local/indigenous knowledge (Bankoff 2004, Barnes et al. 2013, Merli 2012, Heyd and Brooks 2009, Ford et al. 2016). This calls for deeper, more anthropologically oriented explorations and expositions of culturally rooted understandings of environmental processes, changes, and extremes, which can aid the development of more locally appropriate, and therefore more efficacious, strategies for adapting to climate change and reducing disaster risk (Oliver-Smith and Hoffman 2002, Barnes et al. 2013, Ford et al. 2016).

Responding to the crucial needs outlined above, this dissertation aims, firstly, to bring forth culturally rooted local/indigenous understandings of, and engagements with, rainfall-triggered geophysical hazards in changing Himalayan environments. Secondly, it endeavours to use that locally sourced knowledge, in conjunction with Western geoscience and social science, to develop and empirically operationalise an innovative, integrative, and insightful conceptual framework for aiding climate change adaptation and disaster risk reduction among remote high-mountain communities in the Global South.

In pursuance of the above goal, the dissertation addresses the following research questions through in-depth place-based case studies of two remote, traditional, rural, and largely agro-pastoral high-mountain communities in the Indian Himalaya:

i. How do local understandings (traditional or otherwise) of climatic change, hydrometeorological extremes, and associated high-mountain geophysical hazards compare with regional- and local-scale Western scientific understandings?

ii. How do local communities construct and appraise their own adaptive capacities in the face of risks from climate change-related high-mountain geophysical hazards and concurrent social change?

iii. How can community-level climate change adaptation and disaster reduction practically benefit from holistic, grounded, and culturally responsive engagements with risk?

The two case study communities live nearly 1,000 kilometres apart, at altitudes of 1,700-4,000 metres. They are: the Indo-Aryan Garhwālī and immigrant Népālī of the Upper Mandākinī Valley in northern Uttarakhand, Western Himalaya; and the Tibeto-Burman Lāchenpā and Dokpā of the Upper Lāchen Chú Valley in northern Sikkim, Eastern Himalaya (see locations in Fig. 1.1). The former community inhabits a sacred gorge prone to debris flows, earth slides, and flash floods. The gorge is used by several hundred thousand pilgrim trekkers every summer to access the Hindu shrine of Kédārnāth, which is located below a receding glacier (Mehta et al. 2014). It was the main site of the June 2013 debris flow disaster described above, during which high-intensity rainfall triggered an outburst flood from a lake dammed precariously behind a loose moraine of the glacier (Allen et al. 2016, Dobhal et al. 2013). The latter community also inhabits a valley prone to landslides and flash floods, and has been affected by extreme rainstorms in recent years, including in September 2011, when high-intensity monsoon rains contributed to the density and severity of earthquake-induced landslides across Sikkim (DMMC 2012, Chakraborty et al. 2011). Even more significantly, that valley is exposed to the threat of outburst floods from several moraine-dammed glacial lakes, particularly a large one located immediately upstream of the village of Thánggū (Worni et al. 2013, Aggarwal et al. 2017, Govindha Raj et al. 2012, Sharma et al. 2018). The environmental extremes that the former community faced in 2013 are akin to what the latter community might have to face in the not-too-distant future.

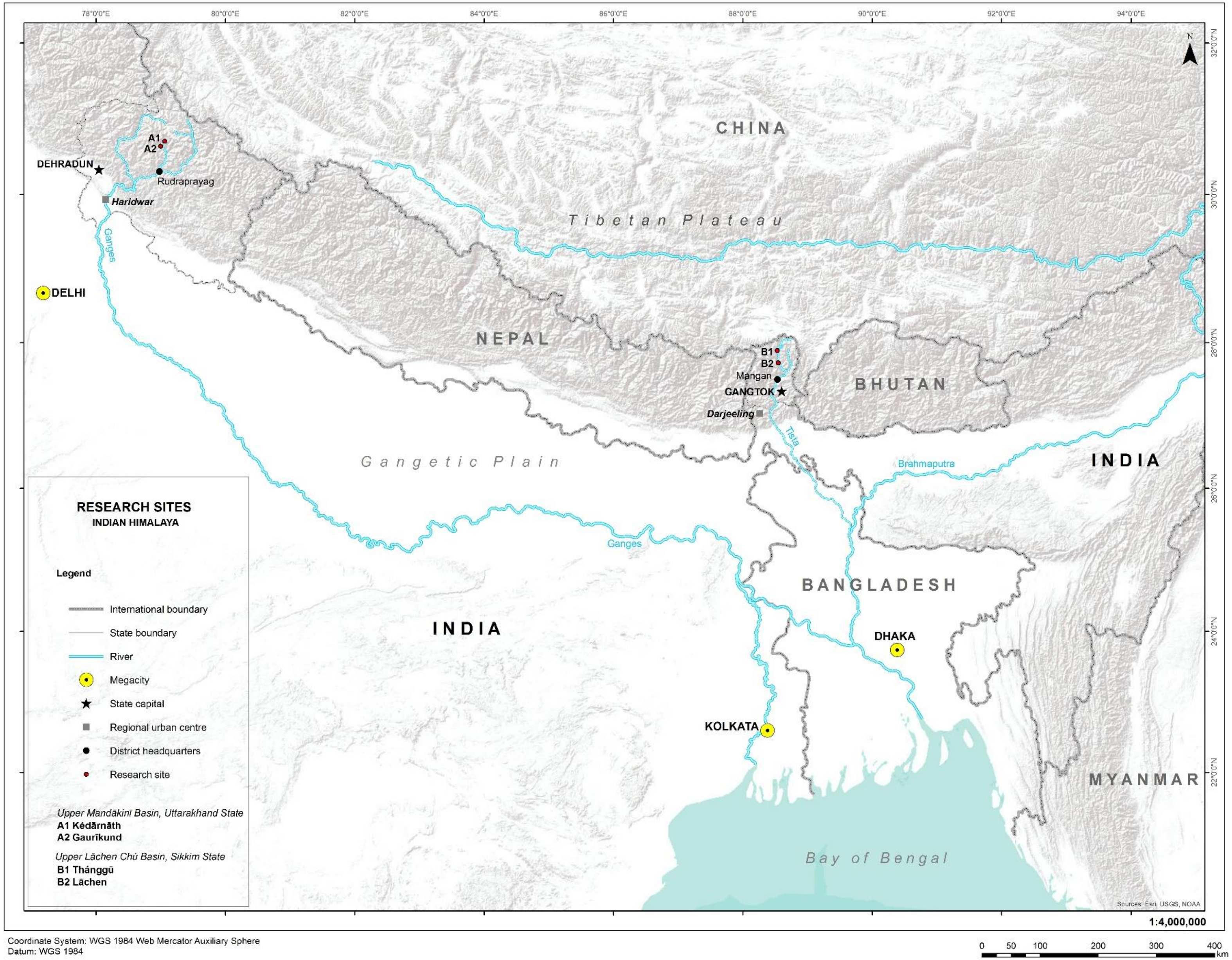


Fig. 1.1. Locations of case study sites in the Indian Himalaya

Before it begins to address the research questions through the case studies, the dissertation provides, in Chapter 2, a cross-disciplinary overview of the fundamental geoscientific and social scientific literatures as well as the conceptual, theoretical and epistemological perspectives that shape the empirical analysis undertaken in Chapters 4-7. It is upon this very knowledge base that the integrative case study methodology of the dissertation also stands, which is presented in Chapter 3.

The execution of the case study methodology commences as Chapters 4 and 5 respond to the first research question. In undertaking a holistic exploration of local experiences of climatic change among the two case study communities, Chapter 4 interweaves data from in-depth community interviews, including ethnographic commentaries on local senses of environmental causality, with primary hydroclimatological analyses focused on rainfall extremes in the summer monsoon as well as reviews of published regional climatological observations and model projections. This integrative, collaborative geoscientific-ethnographic analytical project extends into Chapter 5, where the context shifts to rainfall-triggered geophysical hazards such as landslides and glacial lake outburst floods. As part of its place-based ethnography, Chapter 5 undertakes a spatialised exploration and a geoscientifically aided appraisal of local ontologies of the above hazards as well as local conceptions of landscape dynamics. In so doing, it also engages with understandings of environmental causality that are embedded in geographically referenced folkloristic expressions of traditional metaphysical principles. Moreover, the chapter immerses itself in the subtle psycho-cultural dimension of traditional geographical knowledges, which often transcends the materiality of the environment and the hazards present in it.

To answer the second research question, Chapter 6 sheds light on local perspectives on the two communities' adaptive capacities in all their dimensions, including the neglected but behaviourally potent psycho-cultural one. It continues the ethnographic quest of Chapter 5, exhuming the deep psycho-cultural foundations of the indigenous metaphysics of disaster risk, including the spiritualities, emotionalities, and moralities surrounding vulnerability/resilience. Equally, it appraises the more tangible socio-economic, logistical, and governance-related dimensions of adaptive capacity. The empirical insights gained through Chapter 6 feed into a summary review of both communities' adaptive capacities in Chapter 7. This strategic planning-oriented review uses a practice theory-based conceptualisation of adaptive capacity to operationally integrate the psycho-cultural dimension of adaptive capacity with the more tangible ones. Along with the integrative epistemologies of hazards generated in Chapters 4 and 5, the multi-dimensional, psycho-culturally cognisant review of adaptive capacity ultimately informs the abstractive development of a holistic strategic schema for culturally responsive action towards efficaciously aiding climate change adaptation and disaster risk reduction in remote, traditional high-mountain societies across the Global South. Through this, Chapter 7 addresses the third and final research question. Chapter 8 sums up the findings of the dissertation and articulates its key contributions to knowledge.

Addressing the three research questions entails several kinds of knowledge exchange and conceptual collaboration, which are vital to the philosophical contribution of the dissertation and underpin its engagement with the real world via the case studies. The foremost of these collaborative exchanges is the one between abstractively developed modern/Western knowledges and situationally developed local/indigenous knowledges of risk. Executed throughout the empirical analysis in Chapters 4-7, this exchange consistently advances a pluralist epistemology – one that reflects the acknowledgement that different forms of knowledge can provide equally valid and valuable perspectives in their own right, and that they need not be made to fit in with each other or compete against each other so as to arrive at a singular "truth" (Martin 2012, Ford et al. 2016).

The celebration of multiple coexistent perspectives as a practically useful source of epistemic richness continues in dialogues between academic disciplines within the modern/Western knowledge tradition. At the broadest level, these involve the coming together of the Geosciences and the Social Sciences in the process of understanding human-environment interactions. Within the Geosciences, there is a dialogue between Climatology and Geomorphology, which is carried out in Chapters 4 and 5 to examine atmosphere-landscape interactions, mainly in relation to the hydrometeorological triggering of high-mountain geohazards. Likewise, there are dialogues within the Social Sciences, for example, between Cultural Anthropology and Environmental/Development Studies, which are undertaken in Chapter 6 to understand the role of psycho-cultural factors in shaping communities' adaptive capacities, thereby determining disaster risk. Finally, there is the practical collaboration, in Chapter 7, between climate change adaptation and disaster risk reduction towards their shared strategic goal of vulnerability reduction. Embedded within this collaboration is a practice theory-based conceptual dialogue between the paradigms of vulnerability and resilience, which is effected through the development and operationalisation of a novel integrative conceptual model of adaptive capacity in Chapter 7. Working across epistemic discontinuities with the intention of generating positive practical outcomes for adaptation, therefore, becomes a central theme of the dissertation.

2. Theoretical foundations and literature review

This chapter introduces the fundamental physical scientific and social scientific concepts and theoretical developments that underlie the empirical work contained in Chapters 4-7. It opens with a review of the modern/Western geoscientific literature on the major rainfall-triggered geohazards that affect high-mountain communities as well as the implications of contemporary climate change for the rainfall that triggers those geohazards, also within the regional context of monsoon-affected Himalayan environments. This serves to contextualise the regional- and local-scale assessments of climate change-related hazards undertaken in Chapters 4 and 5. An argument for appreciating and enfranchising alternative, indigenously sourced non-Western-scientific epistemologies of hazards follows, forming the backdrop for the empirical ethnographic work on community-based understandings of geohazards presented in Chapter 5.

Social science literature on human vulnerability, risk, and resilience, mainly from the field of climate change adaptation, is reviewed in the latter half of the chapter. This provides the theoretical foundations for the empirical work undertaken in Chapter 6 towards understanding and managing the human dimension of climate change-linked geophysical risk, which culminates in an attempt, in Chapter 7, at devising a framework for integrated, culturally responsive action towards climate change adaptation and disaster risk reduction.

2.1. Hydrometeorologically triggered geohazards in a changing climate

2.1.1. Modern/Western scientific knowledge

The Intergovernmental Panel on Climate Change (IPCC), the United Nations body for scientifically assessing climate change, its impacts and risks, and possibilities for its management, defines a hazard as *"the potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources"* (IPCC 2012a, p. 560). Using the above definition, hydrometeorologically triggered geohazards may be defined for the purpose of this study as "the potential occurrences of natural or human-induced geological states or events, precipitated or triggered by precipitation, especially extremely intense or prolonged rainfall, which may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources." The above list of elements exposed to the hazard may be expanded to include social structures and relationships (Birkmann et al. 2013) as well as cultural resources, which comprise *"the ways of living involving values, beliefs, practices and material artefacts that condition the production of tangible as well as intangible goods and services needed for the satisfaction of a human group's needs and wants."* (Heyd and Brooks 2009, p. 270). This study examines risks associated with two broad, mutually unexclusive categories of interacting hydrometeorologically triggered geohazards that occur in high-mountain environments: landslides (mainly flows) and glacial hazards (mainly glacial floods).

2.1.1.1. Landslides

Landslides are downslope movements of masses of slope-forming material such as soil, debris, or rock, which always occur under gravity, tend to be aided by water when the material is saturated, and often have well-defined boundaries in the form of shear surfaces (Glade and Crozier 2005, Crozier 1999, Cruden and Varnes 1996, IPCC 2012a). Incorporating a wide range of expressions of slope instability, landslides are commonly classified on the basis of such factors as: (i) material type (e.g. *earth*, typically made of >70% clay/silt/sand and <30% gravel; coarser *debris*, typically made of <70% sand/silt/clay and >30% gravel, cobbles and boulders; and *bedrock*); (ii) rate of movement (with velocities in the order of 10^{-2} – 10^{1} ms^{-1} typically regarded as very – extremely rapid and those in the order of 10^{-8} – 10^{-10} ms^{-1} typically regarded as slow – very slow); and (iii) mechanism of movement (e.g. *fall, topple, slide, flow*), which depends on such factors as geological structure, lithology, slope morphology, vegetation cover, material strength, and external forcing variables such as pore water pressure (Dikau et al. 1996, Cruden and Varnes 1996, Varnes 1978, Hutchinson 1988, Glade and Crozier 2005). External factors such as moisture input exercise considerable control on the mechanism of movement. For example, an intense rainstorm may fully saturate slope-forming material and convert a debris slide into a debris flow, greatly increasing runout in a short span of time (Glade and Crozier 2005).

This study is concerned mainly with rainfall-triggered flow-type landslides, which involve the downslope movement of masses of relatively fluid slope-forming material over relatively rigid underlying beds (Hungr et al. 2001). Building upon the landslide classification schemes of Varnes (1978) and Hutchinson (1988), Hungr et al. (2001) provide an exhaustive review and a systematic genetic and morphological typology of flow landslides. They define and characterise 10 types of flows using the following classes of slope-forming materials: (i) sorted materials (in ascending order of grain size): clay, silt, sand, gravel; (ii) unsorted materials: mud, earth, and debris; (iii) peat; and (iv) rock. Their typology is presented in Table 2.1 below.

Table 2.1. Hungr's classification of landslides of the flow type

Name and definition of landslide class	Material	Water content*	Special condition	Velocity
Non-liquefied sand, silt, gravel, or debris flow Flow-like *movement of loose dry or moist, sorted or unsorted granular material, without significant pore pressure* (p. 226)	Silt, sand, gravel, debris (talus)	Dry, moist, or saturated	No excess pore pressure Limited volume	Various
Sand, silt, debris, or weak rock flow slide *"Very rapid to extremely rapid flow of sorted or unsorted material on granular slopes, involving excess pore pressure or liquefaction of material originating from the landslide source"* (p. 226)	Silt, sand, debris, weak rock	Saturated at rupture surface content	Liquefiable material** Constant water	A few metres per minute to several metres per second
Clay flow slide *"Very rapid to extremely rapid flow of liquefied sensitive clay, at or close to its original water content"* (p. 228)	Sensitive clay	At or above liquid limit*^	Liquefaction *in situ*** Constant water content relative to *in situ* source material	A few metres per minute to several metres per second

Peat flow *"Slow to very rapid flow-like movement of saturated peat, involving high pore pressures"* (p. 229)	Peat	Saturated	Excess pore pressure	A few metres per year to a few metres per minute
Earth flow *"Rapid or slower, intermittent flow-like movement of plastic, clayey earth"* (p. 229) [Equivalent to Hutchinson's (1988) *mudslide*]	Clay or earth	Near plastic limit^*	Slow movements	A few metres per hour or slower
Debris flow *"Very rapid to extremely rapid flow of saturated non-plastic debris in a steep channel (Plasticity Index*** <5% in sand and finer fractions)"* (p. 231)	Debris	Saturated	Established channel Increased water content relative to *in situ* source material	A few metres per minute to several metres (even up to 20 metres) per second
Mud flow *"A very rapid to extremely rapid flow of saturated plastic debris in a channel, involving significantly greater water content relative to the source material (Plasticity Index*** > 5%)"* (p. 232)	Mud	At or above liquid limit*^	Fine-grained debris flow	A few metres per minute or faster
Debris flood *"Very rapid, surging flow of water, heavily charged with debris, in a steep channel"* (p. 233) [Equivalent to Hutchinson's (1988) *hyperconcentrated flow*]	Debris	Free water present	Flood^ (strictly speaking, a non-landslide mass transport phenomenon)	A few metres per minute to several metres per second
Debris avalanche *"Very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope, without confinement in an established channel"* (p. 234)	Debris	Partly or fully saturated	No established channel Relatively shallow, steep source	Several metres per minute to several metres per second
Rock avalanche *"Extremely rapid, massive,* flow-like *motion of fragmented rock from a large rock slide or rock fall"* (p. 235)	Fragmented rock	Various, mainly dry	Intact rock at source Large volume^^	A few to several metres per second

Source: Adapted from Hungr (2001)

*Water content of material close to rupture surface at time of failure
** Observed or implied presence of full or partial *in situ* liquefaction of source material
*^Liquid limit (LL): Upper limit of soil plasticity, representing water content at which behaviour of fine-grained soil changes from plastic to liquid state upon increasing wetness and from liquid to plastic state upon reducing wetness
^*Plastic limit (PL): Lower limit of soil plasticity, representing water content at which fine-grained soil changes from plastic to semisolid state upon reducing wetness and from semisolid to plastic state upon increasing wetness
***Plasticity Index (PI): Range of water content over which soil remains plastic, calculated as difference between LL and PL, generally ranging from >35% (very high plasticity) in clayey (finest-grained) soils to <5% (slight or no plasticity) in coarser sandy soils
^Peak discharge of same order as that of major/accidental flood; significant tractive forces of free-flowing water; presence of floating debris
^^Approximate volume >10,000 m^3; mass *flow*, as opposed to fragmental rock *fall* (see also Whalley 1984)

The stability of a slope (i.e. its propensity to not undergo structural failure or morphologically disruptive change) is often conceptualised in terms of the balance between shear stress (forces enabling the downslope movement of slope-forming material) and shear strength (forces resisting slope failure), with shear strength exceeding shear stress in static slopes (Glade and Crozier 2005). The absolute surplus amount by which shear strength exceeds shear stress (and which, for the slope to fail, must be eliminated through a decrease in shear strength or an increase in shear stress) is termed by Glade and Crozier (2005) as the "margin of stability"

(MoS) against failure. Any slope, according to them, may be seen as existing at a certain point on a continuum that has extremely high margins of stability (implying negligible probabilities of slope failure) at one end and no margin of stability (implying active slope failure) at the other. Based on the potential for dynamic external destabilising forces to induce slope failure, Glade and Crozier (2005; after Crozier 1989) identify three theoretical states of slope stability along the continuum: (i) the *stable* state (an MoS large enough for the slope to withstand any dynamic destabilising processes operating under the current environmental regime); (ii) the *marginally stable* state (an MoS small enough for the currently static slope to be susceptible to active failure whenever any of the external destablising factors crosses a certain threshold value); and (iii) the *actively unstable* state (a zero or near-zero MoS, causing continuous or intermittent mass movement).

Within the context of the three theoretical states of slope stability, Glade and Crozier (2005) identify four groups of factors that promote slope instability: (i) *predisposing* factors (e.g. geological structure, lithology, strength of slope-forming material), which are static and intrinsic to the slope, and affect the MoS by pre-conditioning the slope to respond in certain ways to external, dynamic destabilising forces such as weathering or rainfall; (ii) *preparatory* factors (e.g. long-term sedimentary processes, tectonic uplift, and climatic change; shorter-term human activity-related processes such as deforestation, overgrazing, construction-induced slope disturbances, even anthropogenic climate change), which reduce the MoS without directly initiating (triggering) slope failure, thereby driving stable slopes towards the marginally stable state over time; (iii) *triggering* factors (e.g. high-intensity and prolonged rainfall, rapid snowmelt, earthquakes, volcanic eruptions), which precipitate or directly initiate slope failure, pushing marginally stable slopes into the actively unstable state; and (iv) *sustaining* factors (e.g. post-initiation rainfall activity, terrain changes progressively encountered by the moving mass along its downslope path), which govern ongoing mass movement behaviour (mechanism, velocity, duration, etc.) in actively unstable slopes.

The MoS provides a measure of the responsiveness of a slope to the above destabilising factors. By understanding and quantitatively modelling the relationship between the MoS and the frequencies and magnitudes of destabilising factors, the probability of landslide occurrence can be determined, which is an essential element of hazard assessment (Glade and Crozier 2005). Since a slope generally does not actually fail (i.e. transition from a marginally stable to an actively unstable state) unless the external trigger exceeds a certain critical value, it is useful to focus on examining the empirical relationship between the MoS and the behaviour of the triggering agent, as represented by an extrinsic landslide activation threshold (Glade and Crozier 2005, Schumm 1979).

Landslide activation thresholds based on values of external triggers such as rainfall or seismic shaking offer several valuable opportunities for hazard assessment (Glade and Crozier 2005). Firstly, since the activation threshold varies with the intrinsic stability of the terrain, spatial variations in threshold values may be analysed to discover geographical patterns of landscape susceptibility to landslides (Crozier 1989, Crosta 1998, Glade 1998). Secondly, the rainfall/seismic record for a given terrain may be examined in relation to the corresponding rainfall/seismic landslide activation threshold value so as to make reliable inferences about landslide frequency and even to forecast landslide activity for early warning (Glade et al. 2000, Brooks et al. 2004, Aleotti 2004, Piciullo et al. 2018). However, an important caveat to consider while using triggering thresholds to estimate (future) landslide hazard is the phenomenon of "event resistance" (Crozier and Preston 1999). This refers to situations in which the landslide activation threshold for a given landscape rises over time as material susceptible to landsliding is removed by successive landslide events. For example, if a rainstorm-triggered debris flow removes most of the transportable material that is available on a slope, a future rainfall event of a similar magnitude can be expected to result only in a much smaller (if any) flow until such time as a critical supply of transportable material has been re-established on the slope (Glade and Crozier 2005, Glade 2004).

In the context of hydrometeorologically triggered landslides, activation thresholds represent the lower boundary of rainfall conditions (commonly expressed through power-law relations between rainfall intensity and duration) or associated hydrological or soil moisture conditions that are required to initiate new landslides or re-activate existing ones under a given physiographic regime (Varnes 1978, Crozier 1997, Wieczorek 1996, Reichenbach et al. 1998, Gabet et al. 2004, Guzzetti et al. 2008, Segoni et al. 2018). Numerous studies have examined the relationship between rainfall and landslide activity by empirically determining rainfall-based thresholds for landslide activation at global (e.g. Caine 1980, Innes 1983, Crosta and Frattini 2001, Cannon and Gartner 2005, Guzzetti et al. 2008), regional (e.g. Moser and Hohensinn 1983, Larsen and Simon 1993, Dahal and Hasewaga 2008, Chen et al. 2017, Peruccacci et al. 2017), and local (e.g. Cancelli and Nova 1985, Wieczorek et al. 2000, Bacchini and Zannoni 2003, Sengupta et al. 2010, Kanungo and Sharma 2014) scales. Overall, high-intensity rainfall occurring in short spells (lasting less than a day) and more moderate-intensity rainfall occurring in longer spells (lasting several days) have been found to activate landslides (Wieczorek 1996). Therefore, a future increase in extreme precipitation can be expected to directly amplify the hazard of landslides.

Based on an inventory of 73 sets of rainfall intensity and duration conditions under which shallow landslides and debris flows had taken place around the world, Caine (1980) provided the first global rainfall intensity-duration (ID) threshold curve (representing the lower boundary of rainfall intensity and duration conditions, which, when exceeded, could be expected to activate shallow landslides and debris flows). This takes the form: $I = 14.82 \times D^{-0.39}$ (range: $0.167 < D < 500$), where D represents rainfall duration in hours (h) and I represents rainfall intensity in millimetres per hour (mm h^{-1}). The empirically based equation implies, for example, that a minimum rainfall intensity of 4.29 mm h^{-1} or 102.97 mm day^{-1} for a rainfall duration of 24 h (one day) would be necessary to trigger a shallow landslide or debris flow. Using a far larger global database of 2,626 shallow landslide and debris flow-triggering rainfall events, Guzzetti et al. (2008) have since updated Caine's single-threshold curve to the form: $I = 2.20 \times D^{-0.44}$ ($0.1 < D < 1{,}000$), which predicts landslide occurrence at far smaller rainfall intensities for a given duration than Caine's original threshold (e.g. only 0.54 mm h^{-1} or 13.04 mm day^{-1} for a rainfall duration of 24 h or one day).

Within the Himalayan context, not many more than a dozen studies exist that establish relationships between rainfall and landslide occurrence. Most of these are local-scale (see, for example, Caine and Mool 1982, Froehlich et al. 1990, Bhandari et al. 1991, Gabet et al. 2004, Khanal and Watanabe 2005, Dahal et al. 2006, Sengupta et al. 2010, Kanungo and Sharma 2014, Dikshit and Satyam 2018), with only a couple providing regional-scale rainfall thresholds for landslide activation (pan-Nepal: Dahal and Hasewaga 2008, Eastern

Himalaya: Bhandari et al. 1991). The Himalayan rainfall thresholds for landslide activation that are the most relevant to the case study sites in this dissertation are discussed in Table 2.2 below.

Table 2.2. Some rainfall-based landslide activation thresholds from the Himalaya

Publication	Geographical region / scale / period	Threshold equation and key inferences (n = landslide sample size)	Relevance to case study sites in current dissertation
Dahal and Hasegawa (2008)	Nepal Himalaya / regional-scale (country-wide) / 1951-2006	$\boldsymbol{I = 73.9\ D^{-0.79}}$ * High probability of landslide occurrence if: rainfall intensity ≥ 10.38 mm h^{-1} for a rainfall duration of 12 h, rainfall intensity ≥ 6.00 mm h^{-1} (≥ 144.00 mm day^{-1}) for a rainfall duration of 24 h (1 day), rainfall intensity ≥ 1.68 mm h^{-1} (≥ 40.32 mm day^{-1}) for a rainfall duration of 120 h (5 days) (n = 193)	Region extending from the western boundary of India's Sikkim state (where the Upper Lāchen Chú Basin field sites are located) to the eastern boundary of India's Uttarakhand state (where the Upper Mandākinī Basin field sites lie)
Dikshit and Satyam (2018)	Kalimpong region, Darjeeling Himalaya, West Bengal, India / local-scale / 2010-2016	$\boldsymbol{I = 3.52\ D^{-0.41}}$ * High probability of landslide occurrence if: rainfall intensity ≥ 1.27 mm h^{-1} for a rainfall duration of 12 h, rainfall intensity ≥ 0.95 mm h^{-1} (≥ 22.80 mm day^{-1}) for a rainfall duration of 24 h (1 day), rainfall intensity ≥ 0.46 mm h^{-1} (≥ 11.04 mm day^{-1}) for a rainfall duration of 120 h (5 days) (n = 61) Minimum 10-day antecedent rainfall of 88 mm and minimum 20-day antecedent rainfall of 134 mm required for landslide activation (n = 61)	Landslide sites located within a 100-km aerial distance radius from Eastern Himalayan (Upper Lāchen Chú Basin, Sikkim, India) case study sites; also located in the same wider river basin (Tīstā) as case study sites
Kanungo and Sharma (2014)	Chamoli-Joshimath region Garhwāl Himalaya, Uttarakhand, India / local-scale / 2009-2012	$\boldsymbol{I = 1.82\ D^{-0.23}}$ * High probability of landslide occurrence if: rainfall intensity ≥ 1.03 mm h^{-1} for a rainfall duration of 12 h, rainfall intensity ≥ 0.87 mm h^{-1} (≥ 20.88 mm day^{-1}) for a rainfall duration of 24 h (1 day), rainfall intensity ≥ 0.60 mm h^{-1} (≥ 14.40 mm day^{-1}) for a rainfall duration of 120 h (5 days) (n = 81) Minimum 10-day antecedent rainfall of 55 mm and minimum 20-day antecedent rainfall of 185 mm required for landslide activation (n = 128)	Landslide sites located within a 100-km aerial distance radius from Western Himalayan (Upper Mandākinī Basin, Uttarakhand, India) case study sites; also located in the same Himalayan section (Garhwāl) and the same wider river basin (Alakanandā) as case study sites
Sengupta et al. (2010)	Lanta Khola, North Sikkim, Sikkim Himalaya, India / local-scale / 1998-2006	No typical intensity-duration threshold found suitable for predicting landslide activation (N = 1, single landslide with five reactivation events in study period) Alternative site-specific threshold: $E_{MAP} \geq 0.10$ and $D \geq 15$ days (where E_{MAP} is the ratio of the cumulative rainfall amount for a given rainfall event (E) to the mean annual precipitation amount (MAP); D is the rainfall duration)** Landslide expected to occur if: cumulative rainfall amount ≥ 250 mm over 15 consecutive wet days (MAP for landslide site = 2,500 mm)	Site located within a 50-km aerial distance radius from Eastern Himalayan (Upper Lāchen Chú Basin, Sikkim, India) case study sites; also located in the same river valley and the same wider river basin (Tīstā) as case study sites

*** D = rainfall duration in hours (h), I = rainfall intensity in millimetres per hour (mm h^{-1})**
**Congruent with Bhandari et al.'s (1991) generalised regional thresholds for Eastern Himalaya:
$0.10 < E_{MAP} < 0.20$ for high probability of landslide occurrence; $E_{MAP} > 0.20$ for definite landslide occurrence

A global analysis of fatal non-seismic landslides shows that 4,862 distinct landslide events killed 55,997 people around the world from 2004 until 2016, averaging 4,307 fatalities per year (Froude and Petley 2018). Over three-quarters (79%) of these landslide events were triggered by rainfall, and three-quarters (75%) occurred in Asia, with a very substantial concentration along the Himalayan mountain arc in South Asia (ibid.). Of all the rainfall-triggered landslide events that occurred globally from 2004 until 2016, more than a quarter (26%) were located in India and Nepal, and more than one-fifth (21%) were triggered by seasonal summer monsoon rainfall (June-September) in India and Nepal (ibid.). Monsoon-affected parts of the Himalayan arc are, in fact, the global hotspot for fatal landslides (see also Petley 2012, Petley et al. 2010). Not surprisingly, then, the June 2013 hydrometeorologically triggered periglacial debris flow event at Kédārnāth in the monsoon-affected Indian Himalayan province of Uttarakhand (a case study site for the present study), was by far the deadliest landslide disaster globally in the period 2004-2016 (Froude and Petley 2018, see Allen et al. 2016).

2.1.1.2. Glacial hazards

High-mountain communities, especially those inhabiting periglacial valley environments, tend to be exposed to potentially adverse consequences of active glaciers and associated processes or features that involve snow, ice, permafrost, or meltwater – a set of geohazards known as glacier-related or glacial hazards (Richardson and Reynolds 2000, Reynolds and Richardson 1999, Reynolds 1992; see also Haeberli and Whiteman 2015).

Table 2.3. Richardson and Reynolds' classification of glacier-related hazards

Category	Hazard event	Description	Timescale
Glacier hazards (primary)	Avalanche	Side or fall of a large mass of snow/ice and/or rock	Minutes
	Glacier outburst	Catastrophic discharge of water under pressure from a glacier	Hours
	Jökulhlaup (Icelandic)	Glacial outburst associated with subglacial volcanic activity	Hours to Days
	Glacier surge	Rapid increase in rate of glacier flow	Months to years
	Glacier fluctuations	Variations in ice front positions due to climatic changes, etc.	Years to decades
Glacial hazards (secondary)	Glacial lake outburst flood	Catastrophic outburst from a proglacial lake, typically moraine-dammed	Hours
	Débâcle (French)	Outburst from a proglacial lake	Hours
	Aluvión (Spanish)	Catastrophic flood or liquid mud, irrespective of its cause, generally transporting large boulders	Hours

Source: Reproduced (in part) with permission from Richardson and Reynolds (2000)

Such hazards may either be posed directly by glacial ice or snow, or they may arise indirectly from geophysical processes operating in cryospheric (frozen) environments (Richardson and Reynolds 2000). The former category, described by the above authors as *primary* "glacier hazards", include *avalanches* – extremely rapid slides or falls of large masses of snow or ice, sometimes combined with rock debris; *glacier outbursts* – sudden discharges of water under pressure from a mass of glacial ice; and *glacier surges* – abrupt increases in the rate of a glacier's flow over weeks, months or years. The latter category, described as *secondary* "glacial hazards", includes glacier-related flash floods such as *glacial lake outburst floods (GLOFs)* or catastrophic discharges from all kinds of moraine-dammed lakes; *débâcles* or outbursts emanating specifically from proglacial lakes; and glacial *aluvións* or catastrophic meltwater floods that are typically muddy and carry large boulders, and are therefore a low-viscosity variant of flow-type landslides (see Richardson and Reynolds 2000, Table 2.3). In addition, GLOFs that are powerful enough to entrain very large volumes of morainic or/and glacial outwash sediments (ranging in size from silt to boulders) may turn into proper, viscous debris flows (GAPHAZ 2017, Mehta et al. 2017, Allen et al. 2016).

The origin of a high-mountain glacial flood commonly lies in a proglacial lake (a substantial accumulation of meltwater located in a basin immediately in front of the snout of a glacier), typically one that is dammed by an unstable terminal moraine. However, a range of other potential sources exist, including: (i) other kinds of moraine-dammed lakes (such as those impounded between a valley side and the lateral moraine of a glacier); (ii) ice-dammed proglacial lakes (such as those impounded between a glacier snout and a barrier of glacial ice located perpendicular to it); (iii) ice-marginal lakes (impounded between a valley side and the margin of a glacier); and (iv) structurally weak sections of ice or pools of meltwater that are underneath a glacier (sub-glacial), within it (englacial), or upon its surface (supraglacial) (GAPHAZ 2017, Clague and O'Connor 2015, Bajracharya et al. 2007, Costa and Schustler 1988, Clague and Evans 2000, Walder and Fountain 1997, Warburton and Fenn 1994, Clarke 2002, Clarke 2003).

For a moraine-dammed lake to drain catastrophically by means of a GLOF, the hydrostatic pressure needs to exceed the restraining lithostatic pressure, which results in the failure of the debris barrier that impounds the water (Richardson and Reynolds 2000). The moraine dam may be internally destabilised by such processes as warming-induced thawing of ice cores, settlement of the moraine and a resultant reduction of dam height, and piping or leakage of water through the moraine wall (Clague and Evans, 2000). However, the most common mode of moraine dam failure is externally induced overtopping and rupturing, which typically involves a sudden mass influx into the lake, the generation and propagation of impulse waves across the lake, and, finally, the creation of a spillway through the destabilised (often completely crumbled) moraine ridge (Clague and Evans 2000, Richardson and Reynolds 2000, Roberts 2005, Worni et al. 2013, GAPHAZ 2017). The sudden mass influx generally occurs as the displacement of a large volume of lake water following the impact of a mass movement upon the lake (e.g. from a rainfall-triggered or seismically induced ice avalanche or scree slope failure). It may, however, also be in the form of a rapid meltwater discharge into the lake (e.g. from high-intensity rainfall over a contiguous glacier's ablation area; from the abrupt drainage of another pool of meltwater located upstream of the lake; or simply from accelerated ice-surface melting caused by high temperatures) (ibid.).

Ice slides/avalanches, which involve the detachment of masses of ice from steeply sloping glaciers and their downward motion under gravity, are the most common type of GLOF-inducing mass influx into moraine-dammed proglacial lakes, both globally and within the Himalaya (Alean 1985, Clague and Evans 2000, Richardson and Reynolds 2000). This is because the upslope recession of a large proportion of glaciers since the end of the Little Ice Age in the late 19th century has taken place over steep rock slopes, causing deep crevasses and fragile ice columns known as séracs to develop in many glacier snouts that hang precariously over proglacial lakes (Clague and Evans 2000).

Floods from ice-dammed lakes tend to be characterised by smaller peak discharges and come about less catastrophically than "outbursts" (GLOFs) from moraine-dammed lakes, because complete mechanical collapses of dams of hard ice are very rare (Clague and Evans 2000). As opposed to the explosive lake-emptying discharges that generally take place through ruptured dams of morainic debris, flood discharges from ice-dammed lakes are often only rapid leakages via the interface between the edge of the glacial ice and the valley side, involving no more than a partial mechanical failure of the ice barrier (Walder and Costa 1996, Clague and Evans 2000). Occasionally, the ice dam may undergo flotation and the lake may drain subglacially via tunnels that expand as increasing volumes of water flow through them – a situation that is normally still not as catastrophic as an outburst flood from a moraine-dammed lake (Clarke 1982, Björnsson 1974). Also normally not as hazardous as GLOFs, glacier outbursts are another mode of extremely rapid meltwater discharge. Operating without meltwater storage in surficial lakes, they commonly result from major expansions or explosions of small pockets or conduits of meltwater within the glacier such that the hydrostatic pressure exceeds the confining cryostatic pressure (Richardson and Reynolds 2000, Haeberli 1983).

This study focuses on GLOFs, because these are the deadliest glacial hazard in the Himalaya (see Carrivick and Tweed 2016), where hundreds of perilously moraine-dammed meltwater lakes have been expanding as a result of climate warming-induced glacial recession, especially since the 1970s (Bolch et al. 2019, Krishnan et al. 2019, Bolch et al. 2012, Ives et al. 2010, Bajracharya et al. 2007, ICIMOD 2003, 2004, 2005, Aggarwal et al. 2017, Komori 2008). With over 5,000 fatalities, the June 2013 extreme rainfall-triggered flash-flooding and landslide event in northern India, which involved the catastrophic drainage of a moraine-dammed lake in the glacierised Western Himalayan valley of Kédārnāth (one of the case study sites for the dissertation), was the deadliest fluvial disaster in South Asia since 1980 (EM-DAT data, cited in Bubeck et al. 2017) as well as the deadliest and most damaging glacial flood ever recorded in Asia (Carrivick and Tweed 2016, see Allen et al. 2016).

Since moraine dams often fail when mass movements (especially ice slides/avalanches from hanging or calving glaciers) suddenly make their way into lakes, and since catastrophic mass movements in Himalayan settings are commonly triggered by high-intensity summer monsoon precipitation, GLOFs may be regarded as a hydrometeorologically activated/influenced gohazard in the Himalaya (Richardson and Reynolds 2000, GAPHAZ 2017, Bolch et al. 2019, Froude and Petley 2018). In this context, Richardson and Reynolds' (2000) analysis of 26 twentieth-century Himalayan GLOF events reveals that all of these events occurred between June and October – during and immediately following the summer monsoon season, when high temperatures combine with intense and prolonged rainfall to elevate rates of ablation (ice loss by melting, sublimation, calving, etc.), meltwater discharges, lake water levels, and instability of glacierised and non-glacierised slopes. Likewise, in other mid-latitude mountain environments such as the Swiss Alps and the US Cascades, positive relationships have been observed between summer/early autumn episodes of extremely high temperatures or/and rainfall and occurrences of glacier outbursts, which have been explained by elevated volumes of meltwater or/and rainwater making their way to glacier beds via crevasses and moulins (Warburton and Fenn 1994, Walder and Driedger 1995). These facts suggest that a future increase in hydrometeorological extremes, especially when combined with anomalously high temperatures, can be expected to exacerbate glacial hazards, including GLOFs.

2.1.1.3. Climate change and geohazard-triggering rainfall

Each year, disasters triggered by extreme rainfall result in thousands of fatalities, large-scale health impacts, and tens of billions of US dollars' worth of damage globally (CRED and UNISDR 2019, Ahern et al. 2005). According to the International Disaster Database (EM-DAT) of the Centre for Research on the Epidemiology of Disasters (CRED), the average numbers of persons affected and killed annually by the combined impact of storms, floods, and landslides were 121 million and 19,075, respectively, in the period 2000-2017 (CRED and UNISDR 2019). Flooding alone globally affected an average of nearly 87 million people per year between 2000 and 2017 (ibid.). Asia accounted for an estimated 62% of global financial losses associated with flooding between 1980 and 2015 (EM-DAT data, cited in Bubeck et al. 2017). Of the 10 deadliest fluvial floods between 1980 and 2016, seven took place in Asia and four of these were within densely populated, monsoon-affected South Asia (ibid.). As mentioned above, the June 2013 extreme monsoon rainfall-triggered flash-flooding and landslide event in northern India, which devastated the Western Himalayan case study area chosen for the present study (see Allen et al. 2016), was the most fatal fluvial disaster in South Asia since 1980 (EM-DAT data, cited in Bubeck et al. 2017). This is why, in trying to understand such geohazards, it is necessary to consider in some detail the implications of climate change for hydrometeorological extremes.

Temperature rise and precipitation extremes

Human-induced increases in atmospheric concentrations of greenhouse gases have been shown to have contributed not only to global climate warming, but also to the intensification of observed daily extreme precipitation in the second half of the 20th century over about two-thirds of the data-covered Northern Hemisphere land area (Min et al. 2011, see also Seneviratne et al. 2012, IPCC 2013, Alexander et al. 2006). Moreover, robust evidence from around the world has linked specific recent extreme weather events (including precipitation extremes) or their increased frequency to anthropogenic climate change (Coumou and Rahmstorf 2012). One such event attribution study links the aforementioned June 2013 extreme precipitation event in northern India to post-1980 anthropogenic climate change-induced modification of regional summertime upper tropospheric circulation (Cho et al. 2016).

A statistically significant global-scale positive relationship has been observed between atmospheric temperature and precipitation extremes over the 20th and early 21st centuries, with the median intensity of annual maximum daily precipitation varying in proportion with changes in globally averaged near-surface temperature at a rate of between 5.9% and 7.7% per °C (Westra 2013). Results from global climate models (GCMs) also indicate that extreme daily rainfall intensities can be expected to increase with climate warming at similar rates (averaging ~6% per °C) over the 21st century (Kharin et al. 2007, see also Meehl et al. 2007, Pall et al. 2007, Allen and Ingram 2002). This broadly conforms to the thermodynamic Clausius-Clapeyron equation, according to which the moisture-holding capacity of air varies directly with its temperature at a rate of about 7% per °C, implying that precipitation extremes may theoretically be expected to intensify at a comparable rate in response to climate warming (Trenberth et al. 2003).

Recent research shows that climate warming is likely to cause particularly pronounced increases in very short-duration, sub-diurnal (hourly and even sub-hourly) extreme precipitation, which may have direct implications for the magnitude and frequency of flash floods and other precipitation-triggered geohazards such as landslides (Westra et al. 2014, Panthou et al. 2014). Overall, hourly rainfall extremes have been observed to increase with temperature at approximately the Clausius-Clapeyron rate of 7% per °C for temperatures of up to 12°C, and at significantly higher rates of up to double the Clausius-Clapeyron rate (14% per °C) for temperatures higher than 12°C (Lenderink and van Meijgaard 2010, 2008; Berg et al. 2013, Molnar et al. 2015). This acceleration has been attributed to the higher likelihood of convective rather than large-scale stratiform rainfall under warmer conditions as well as a positive feedback from the dynamics of convective clouds (Haerter and Berg 2009, Berg et al. 2013, Moseley et al. 2013, Lenderink and van Meijgaard 2010, Loriaux et al. 2013; see also Westra et al. 2014). For temperatures exceeding an approximate threshold of 22-24°C, however, there is evidence of the relationship between temperature and extreme rainfall intensity leveling off or even becoming inverse, possibly due to decreases in moisture supply at such high temperatures (Hardwick-Jones et al. 2010, Lenderink et al. 2011, Utsumi et al. 2011, Berg and Haerter 2013).

The climatological context of Himalayan geohazards

In the regional context of the Himalaya, the June-September summer monsoon season accounts for almost all extreme precipitation events that trigger flash floods and landslides as well as roughly 60-80% of the mean annual precipitation amount (typically 1,000-3,000 mm) and runoff in the central segment of the mountain chain, where the two case study communities are situated (Krishnan et al. 2019, Kanungo and Sharma 2014, Sengupta et al. 2010, Petley et al 2007, Shrestha et al. 2000). During May-June, the intertropical convergence zone shifts northwards all the way up to the sweltering Indus-Ganges-Brahmaputra Plain and the southern edge of the Himalaya, preparing the region for the arrival of tropical monsoon rainstorms from the Indian Ocean. High-intensity monsoon precipitation tends to occur over the Himalayan region particularly when vigorous, moisture-laden tropical east-southeasterly monsoonal low-pressure systems from the Bay of Bengal (and, in the Western Himalaya, also southwesterly monsoonal depressions from the Arabian Sea) interact with synoptic extratropical upper-tropospheric westerly circulation systems (see Vellore et al. 2016). It was precisely such an interaction between a tropical east-southeasterly depression from the Bay of Bengal and a mid-latitude westerly trough over northern India that led to the June 2013 extreme rainfall-triggered flash-flooding and landslide disaster that devastated the Western Himalayan case study area chosen for the present study (see Joseph et al. 2015).

By late September or early October, the monsoon rains withdraw completely from the region, and a relatively warm and dry two-month post-monsoon season follows, with November being the year's driest month by far, except in the rare event of a major tropical cyclone landfall (see Krishnan et al. 2019, Petley et al. 2007). The December-April winter-spring season in the Central Himalayan region sees mainly extratropical precipitation, received largely as snowfall at elevations of over 3,500 metres. This precipitation accounts for roughly 20-40% of the mean annual precipitation amount and comes almost exclusively from synoptic mid-latitude westerly storms known regionally as "western disturbances" (see Dimri et al. 2015). These storms involve the eastward propagation of large-amplitude wave disturbances along the subtropical westerly jet stream from over the Mediterranean and Black Sea regions, across West-Central Asia and the Hindu Kush – Karakoram – Western Himalayan region, and all the way down to the eastern end of the Himalayan chain, where they eventually dissipate (Dimri et al. 2015, Madhura et al. 2015).

Overall, both the total annual precipitation and the contribution of summer monsoon precipitation to it increase from west to east along the Himalayan mountain system, implying that the precipitation regime of the Eastern Himalayan Upper Lāchen Chú Basin study area (Sikkim state) is more strongly influenced by the tropical summer monsoon and considerably less so by wintertime extratropical "western disturbances" than that of the Western Himalayan Upper Mandākinī Basin study area (Uttarakhand state) (see Krishnan et al. 2019; see also Hasson et al. 2014). However, the above west-east pattern is only synoptic in that there are significant local-scale orographic/topography-related precipitation variations across the monsoon-affected Himalaya (see Bookhagen et al. 2005). Further, there is an arid trans-Himalayan rain-shadow belt running all along the northern/Tibet side of the entire High Himalayan chain, which generally remains beyond the reach of tropical monsoon storms (see Krishnan et al. 2019).

Summer monsoon precipitation since the 1870s, averaged for the whole of India, has remained remarkably stable and shows no long-term trend (Krishna Kumar et al. 2011a, 2011b; see also Pant and Rupa Kumar 1997). However, monsoon precipitation does exhibit some multidecadal-scale alternations between strings of years with relatively frequent droughts (weak monsoons) and those with relatively frequent floods (strong monsoons) (ibid.). Although no simple relationship exists between the strength of the South Asian summer monsoon and the El Niño Southern Oscillation (ENSO), severe droughts in the subcontinent since the 1870s have always coincided with El Niño events, especially those involving particularly large positive seas surface temperature anomalies in the central equatorial Pacific rather than in the far-eastern equatorial Pacific (Krishna Kumar et al. 2006).

Petley et al. (2007) observe over 1978-2005 a cyclical trend in the occurrence of fatal landslides in Nepal that is strongly aligned to interannual fluctuations in the strength of the summer monsoon, as indicated by two subcontinent-scale indices – the rainfall intensity-based All India Monsoon Rainfall Index and the atmospheric circulation-based South Asian Summer Monsoon Index. Remarkably, the strong relationship found by Petley et al. (2007) between subcontinent-scale monsoon strength and the number of fatal landslides in Nepal is inverse rather than positive. This seemingly counterintuitive observation, they argue, may be explained through an inverse relationship between subcontinent-wide monsoon strength and the amount of monsoon precipitation received regionally in the mid-Himalayan belt of Nepal. In other words, a monsoon that is relatively weak at the subcontinental scale can be expected to coincide with relatively heavy June-September rainfall in the Nepal Himalaya and therefore a relatively large number of fatal rainfall-triggered landslides in the region. Since the two case study regions for this dissertation are contiguous with the Nepal Himalaya (i.e. located immediately east and west of Nepal's eastern and western frontiers respectively), this finding is highly relevant to an analysis of climate-related risks for those regions.

Petley et al. do not delve into the atmospheric dynamics behind the occurrence of regionally heavy, geohazard-triggering rainfall in the Central Himalaya during monsoons that are weak overall. However, the present review finds that it may be worthwhile for future atmospheric research to explore the *potential* relationship of a relatively weak South Asian summer monsoon with: (i) greater seasonal warming and stronger convection along the Himalayan foothills; (ii) an enhanced role of the aforementioned mid-latitude upper-tropospheric westerly depressions (transported along the subtropical westerly jet stream) in intensifying summer precipitation over the Himalaya (see Vellore et al. 2016); and (iii) an amplification of the above summertime interactions between extratropical upper-tropospheric and tropical monsoon circulation systems in the context of such factors as upper-tropospheric Rossby wave patterns, the latitudinal position of the subtropical westerly jet stream, teleconnections involving the North Atlantic Oscillation (NAO) and ENSO, and regional climate change impacts on upper-tropospheric circulation as well as on teleconnection processes (see Lau and Kim 2012, Syed et al. 2010, 2006, Archer and Fowler 2004, Krishna Kumar et al. 2006, Paeth et al. 2008, Cho et al. 2016).

Since the mid-20th century, the character of summer monsoon precipitation in the Indian subcontinent has changed such that the frequency and intensity of daily heavy precipitation has increased, and so has the contribution of short-spell high-intensity precipitation events to seasonal precipitation (Goswami et al. 2006, Dash et al. 2011). Likewise, the Himalayan region has, on the whole, seen a significant increase in extreme precipitation along with a trend towards wetter monsoons since the 1960s, even despite a slight regional-scale weakening of the monsoon over the past century (Zhan et al. 2017, Ren et al. 2017, Krishnan 2019). This has coincided with the Himalaya having warmed up at a regionally averaged rate of about 0.2°C per decade since the mid-20th century, which is roughly equivalent to the average rate of global land surface warming (Ren et al. 2017).

At high altitudes such as those of the two case study areas for this dissertation (3,000-5,000 metres), even sharper temperature increases (~0.3-0.5°C per decade) and therefore greater precipitation intensification may be expected to have occurred since the mid-20th century, considering robust regional evidence of climate warming rates varying directly with altitude (see, for example, Yan and Liu 2014, Liu et al. 2009, Shrestha and Devkota 2010; see also Ren et al. 2017). Moreover, climate warming across the Himalayan region has accelerated sharply since the 1980s, with annual mean temperatures increasing at a regionally averaged rate of 0.6°C per decade in the period 1982-2006, which is considerably higher than the global rate of land surface warming (Shrestha et al. 2012). A corresponding acceleration of precipitation intensification has been observed across the Himalayan region since the mid-1980s (Ren et al. 2017).

The above trends towards a warmer regional climate with heavier and more extreme monsoon precipitation are projected by global and regional climate models (GCMs and RCMs) to continue over the 21st century under the various scenarios/trajectories of greenhouse gas emissions/concentrations defined by the IPCC (Krishnan et al. 2019, see Chapter 4 for details).[*] Overall, this implies that the regional climate of the Himalaya is characterised in modern/Western science as one that is changing such that high-mountain environments can be expected to be thermally destabilised and become significantly more susceptible to slope- and flooding-related geohazards that are triggered by high-intensity rainfall.

[*] A summary of the IPCC's greenhouse gas emissions scenarios, which are based on a range of future global socio-economic conditions defined in its Special Report on Emissions Scenarios (SRES, IPCC 2000) and were used for climate projections in its third and fourth assessment reports of 2001 and 2007, is available in Appendix 1A. A summary of the IPCC's representative concentration pathways (RCPs) for atmospheric greenhouse gas concentrations, which are based on a range of future emissions trajectories and associated climate forcing used for climate projections in its fifth assessment report of 2014 (IPCC 2013), is available in Appendix 1B. Reviews of regional climate projections based on IPCC scenarios/pathways can be found in Appendices 4A.2 and 4B.2.

2.1.2. Missing local epistemologies: The need for "two-eyed seeing"

Western science objectively demonstrates the probability and inherent character of climate change-related geohazards, but a hazard ultimately matters for how it affects people's lives. An emerging body of research shows that psycho-cultural factors, such as metaphysical convictions and worldviews rooted in religion, are central to how many traditional societies conceive of, respond to, and live with environmental hazards (Schipper et al. 2014, Schipper 2010, Gaillard and Texier 2010, Bankoff 2004, Schlehe 2010, Bjønness 1986, Crosby 2008, Sherry and Curtis 2017, Bachri et al 2015, Lavigne et al. 2008, Mitchell 2000). Consequently, there has been a push by academics, especially over the last decade, for greater anthropologically oriented engagement with traditional belief-based constructions and culturally embedded experiences of hazards as part of mainstream climate change and disaster research (Barnes et al. 2013, Merli 2012, Orlove et al. 2019, Oliver-Smith and Hoffman 2002, Gaillard and Texier 2010, Chester 2005). Nonetheless, interactions of traditional cultures with environmental hazards, especially in the context of rapid social and environmental change, remain incompletely understood and scarcely represented in the literature. This lack of analytical engagement seems to be due, at least in part, to the subtle complexities of behaviourally potent nature-related ontologies, religious beliefs, mythologies, symbologies, values, moralities, emotionalities, and spiritualities, which are often only appreciable emically (see Nunn 2014, Schlehe 2010, Bjønness 1986, Crosby 2008, Loza et al. 2016, Sherry and Curtis 2017). In this context, Bankoff (2004, pp. 91, 92) observes:

"The social construction of hazard in a society is not just of mere academic interest but should also be a matter of considerable moment for those engaged in disaster preparedness, management and relief. All too often, insufficient recognition is accorded to the manner in which people's actions before, during and after a disaster are influenced by their cultural interpretation of what they are experiencing, whether the event is perceived to be an unavoidable climatic or seismic extreme or a just form of retribution meted out for a community's transgressions. Behaviours that appear inappropriate or illogical to external agencies or relief workers may be entirely consistent and rational actions when understood in the context of the operating schema of the individuals experiencing such phenomena."

Not surprisingly, emic perspectives on environmental change impacts facing indigenous/traditional societies remain generally underappreciated and epistemologically disempowered in the assessment reports of the IPCC, which are instrumental in setting global and regional policy agendas on climate change (Ford et al. 2016). Traditional environmental ontologies and knowledges from outside the circumpolar (Arctic) regions, Australasia, Latin America, and Africa are particularly underrepresented within and beyond IPCC assessments (Ford et al. 2016, Alexander et al. 2011).

In comparison with traditional climatological (temperature-, precipitation-, and ice/snow-related) and ecological (biodiversity-, ecosystem-, and natural resource management-related) knowledges, traditional geological knowledge (especially that relating to climate-related geomorphological dynamics and geohazards) has been conspicuously overlooked within climate change impacts research (see, for example, Alexander et al. 2011). This may be because traditional knowledge of the geophysical environment often exists in such inexplicit, coded forms as geomorphically referenced religious folklore, mythically expressed understandings of landscape dynamics, and geologically embodied and symbolised spiritual or metaphysical principles (see, for example, Nunn 2014, Schlehe 2010, Bjønness 1986). Accessing such knowledge, spatially contextualising it, reliably representing it in formats that are communicable to modern materialist epistemic cultures, and then systematically examining it in relation to corresponding modern/Western scientific knowledge may not be easy without an intimate appreciation of both traditional/indigenous culture/philosophy and modern/Western geoscience. This is a crucial empirical challenge that this dissertation takes up in Chapter 5.

The few ethnographic accounts of traditional ontologies/knowledges of geophysical environments that do exist are mostly in the context of volcanic and seismic hazards (see, for example, Lavigne 2008, Schlehe 2010, Cashman and Cronin 2008). However, a handful of exceptions exist beyond those contexts, including a study of traditional geological myths recalling rapid coastal changes that occurred several thousand years ago in the Asia-Pacific region (Nunn 2014), as well as work on traditional cultural "perceptions" (Bjønness 1986) and "interpretations" (Sherry and Curtis 2017) of mountain hazards among Buddhist Sherpa communities in the Nepal Himalaya.

A notable feature of Bjønness' (1986) place-based ethnography is the observation that the Sherpa of the Nepal Himalaya perceive the dynamics of their geophysical environment in a dualistic manner, interpreting hazards such as landslides, avalanches and flash floods concurrently in terms of natural (material, earthly) processes and supernatural (invisible, divinely operated) forces. These perspectives are found, respectively, to motivate practical actions intended to mitigate the physical impact of hazards and religious responses intended to neutralize the invisible forces. Similar dualistic understandings of geohazards have also been discussed in more recent ethnographically oriented work with Nepalese Sherpa communities in the context of landslides (Oven 2009) and glacial lake outburst floods (Sherry and Curtis 2017). The latter two geographical studies seem to approach geohazards from very mildly social constructionist standpoints in that they do not directly refer to local contextual, placed-based knowledge of hazards as mere perception. However, much like Bjønness' fairly realist appraisal of "hazard perception" (where the reality of the hazard itself is represented by Western science and is assumed to exist independently of local communities' perceptions), neither of them thoroughly engages with the metaphysical meanings embedded in the beliefs and practices (including religious rituals) that constitute the traditional culture's interaction with geohazards, especially in the context of rapid social change and the associated spread of materialist modernity. Arguably, more immersive social/cultural anthropological approaches can fill this gap in place-based hazard research (for rare examples of these, see Schlehe 2010, Smadja 1997).

Within the Himalayan context, a number of other recent studies comprehensively explore local communities' *perceptions* of geohazards in relation to Western geoscientific hazard assessments, including in spatial formats (see Ahmed et al. 2019, Sherpa et al. 2019, Kaul and Thornton 2014, Sudmeier-Rieux et al. 2012). However, apart from the fact that they consciously take markedly realist ontological stances on geohazards, these practically oriented engagements with local knowledge are simply not ethnographic enough to be able to deeply examine the cultural contexts within which the hazards may have been conceived of or indeed "constructed" (see Dake 1992). The dearth of culturally immersive geohazard research tends to reinforce the firmly established view that a hazard itself exists "out there" as an absolute and independent physical reality defined and explained by modern materialist science, and that alternative place-based knowledges of that reality only entail perception (and not definition) of the hazard or its absence (see Fox 1999).

The positivist undermining of local/indigenous ways of knowing about geohazards is a critical research challenge that the dissertation attempts to address. It does so by proposing a pragmatic pluralist epistemology of the physical landscape – one based on the acknowledgement that both abstractively built modern/Western scientific knowledge and situationally built local/indigenous knowledges offer equally valid and valuable perspectives in their own right, and that they need not be made to fit in with each other or compete against each other so as to arrive at a singular "truth" (Martin 2012, Ford et al. 2016). Such attempts at embracing diverse, even contradictory, knowledges and perspectives – to understand the world in more than one way at the same time – have been termed by Bartlett, Marshall and Marshall's (2007, 2012) hybrid Western-Indigenous scholarly team as "two-eyed seeing". In the words of Martin (2012, p. 31):

"Two-eyed seeing stresses the importance of being mindful of alternative ways of knowing (multiple epistemologies) in order to constantly question and reflect on the partiality of one's perspective. It values difference and contradiction over the integration or melding of diverse perspectives, which can result in the domination of one perspective over the others. As a result, one "eye" is never subsumed or dominated by the other; rather, each eye represents a way to see the world that is always partial. When both eyes are used together, this does not mean that our view is now "complete and whole," but a new way of seeing the world has been created – one that respects the differences that each can offer."

This pluralistic way of knowing the world could allow both holders of modern/Western scientific knowledge (such as external researchers or administrators with modern academic degrees) and bearers of traditional/indigenous experiential knowledge (such as local community elders) to become more critically aware of their own fixed, deep-seated frames of reference and to enrich their worldviews with novel, practically useful perspectives borrowed from "the other" (Bartlett et al. 2015, see also Tomaselli et al. 2008, Loppie 2007). In the context of understanding climate change and geohazards, such reflexive "co-learning" (Bartlett et al. 2015) could, in particular, help modern science come to terms with the intricate webs of place-based emotionalities and spiritualities that tend to surround traditional environmental "wisdom", while encouraging local knowledge systems to appreciate the sophisticated mechanistic models of landscape dynamics offered by "science" (see Bartlett et al. 2012, Bartlett 2011, Barnes et al. 2013, Lövbrand et al. 2015, Ford et al. 2016). Consequently, an integrative "two-eyed" view of the environment could improve community-level management of climate change impacts and disaster risk by making exogenous modern science-based interventions more compatible with local/indigenous cultures and traditional communities more accepting of modern science (see Watanabe et al. 2016, Xu and Grumbine 2014, Kaul and Thornton 2014, Johnston 2015).

2.2. Vulnerability, resilience, adaptation, and risk reduction

Moving on from Western scientific and indigenous conceptual engagements with climate change-related geophysical *hazards*, this section theoretically examines the key perspectives on the human dimension of environmental risk – *vulnerability* and *resilience*. After defining the two concepts and their relationships with *risk*, it advances another kind of "two-eyed seeing". This involves the use of *adaptive capacity* as a conceptual tool and *practice theory* as a theoretical medium to epistemically integrate vulnerability-based and resilience-based approaches to climate change adaptation.

2.2.1. Key concepts

Vulnerability and risk

The Intergovernmental Panel on Climate Change (IPCC) provides two distinct definitions of human vulnerability:

A. *"The propensity or predisposition to be adversely affected"* (IPCC 2012a, p. 564);

B. *"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity"* (IPCC 2001, p. 995; IPCC 2007a, p. 883).

The latter definition echoes the widely accepted view that vulnerability is shaped by the interplay of three properties: (i) *exposure* ("the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected": IPCC 2012a, p. 559); (ii) *sensitivity* (an intrinsic feature of the system, identical to vulnerability in Sense A of the term) to one or more hazards (potentially harmful occurrences); and (iii) *adaptive capacity* (Yohe and Tol 2002, Smit and Wandel 2006). Adaptive capacity, in the context of actual or expected climate change, refers to *"the combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities"* (IPCC 2012a, p. 556). Since adaptive capacity regulates the levels of both exposure and sensitivity, it exercises extensive influence over vulnerability (Yohe and Tol 2002, Adger et al. 2007, see illustration in Engle 2011). It is generally agreed that vulnerability is inversely related to adaptive capacity (Cardona et al. 2012).

Brooks (2003) affirms that the IPCC definitions are based on two distinct conceptualisations of vulnerability in the climate change literature - *biophysical* and *social*. Biophysical vulnerability is understood in terms of the potential impact or outcome of a hazard (e.g. fatality, morbidity, loss of livelihood resources), which arises from the interaction of the hazard (e.g. extreme precipitation, drought) with social vulnerability (e.g. homelessness, hunger). This view of vulnerability is reflected in Definition B above. Social vulnerability (determined by such factors as population structure, socio-economic conditions, access to infrastructure, governance regimes, political dynamics, cultural values and norms) is a state intrinsic to the system (household, community, society, organisation, etc.); it is not a function of the hazard, even though it may be hazard-specific. It includes all those hazard-independent system properties that impact on the outcome. This view of vulnerability is reflected in Definition A above.

Both varieties of vulnerability have traditionally been studied within the context of hazards, and conceptualised as critical constituents of *risk* (Brooks 2003, Brooks et al. 2005). Sarewitz et al. (2003) identify two distinct understandings of risk - *event risk* and *outcome risk*. Event risk refers to the probability of occurrence of a hazard (regardless of its consequence), whereas outcome risk refers to the probability of a particular consequence or impact (which may be a disaster). The likelihood associated with the hazard (event risk) and the inherent properties of the exposed system (social vulnerability) jointly produce outcome risk. Therefore, outcome risk is conceptually equivalent to *risk* defined as (i) a function of hazard, exposure, and [social] vulnerability (see, for example, Crichton 1999, IPCC 2014), and as (ii) the product of probability (or likelihood) and consequence (or impact or loss) (see, for example, Smith and Petley 2009, Jones and Boer 2004, IPCC 2014). Outcome risk is also largely indistinguishable from biophysical vulnerability because both are determined by the inherent system characteristics (social vulnerability, comprising sensitivity modulated by adaptive capacity) as well as the hazards to which the system is exposed (Brooks 2003).

Resilience

The IPCC (2012a, p. 563) defines resilience as *"the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions"*. It defines coping capacity as the ability of an individual or any social unit or system to use *"available skills, resources, and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning in the short to medium term"* (IPCC 2012a, p. 558). Whereas coping capacity is concerned with immediate to medium-term remedial responses to adverse conditions, resilience here relates to longer-term persistence in the face of change. Even though the above definition emphasises the system maintenance (Holling 1973) or functional persistence (Pelling 2011) aspect of resilience, the concept has been broadened to include the possibility of systemic shifts to new stable states when the original state becomes untenable and springing back to it is no longer desirable (Folke 2006). Such shifts are known as transformations; they involve the *"altering of fundamental attributes of a system (including value systems; regulatory, legislative, or bureaucratic regimes; financial institutions; and technological or biological systems)* (IPCC 2002a, p. 564).

The incorporation of the capacity for fundamental systemic *transformations* (as well as incremental or less radical systemic adjustments known as *transitions*) into resilience (see, for example, Nelson et al. 2007, and the revised definition of resilience in IPCC 2014) makes it a universally desirable property as opposed to a purely system-maintaining resilience, which might, at times, become undesirable. This leads to considerable overlap between resilience and adaptive capacity (which is always described as a desirable system property), making it difficult to distinguish between the two concepts (Engle 2011). Even greater confusion arises from the semantically induced disagreement over whether coping capacity and resilience are embodied in adaptive capacity (as contended by Gallopín 2006), or whether coping capacity and adaptive capacity are embodied in resilience (as contended by Turner et al. 2003). The IPCC (2014, p. 1772) seems to endorse the latter view through its latest conceptualisation of resilience as *"the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation."*

2.2.2. Combining vulnerability and resilience thinking for adaptation

Human vulnerability has been studied extensively in the context of climate change and hazards since the 1980s (see, for example, Chambers 1989, Pelling 1997, Adger 2006, Birkmann et al. 2013). The relationship between vulnerability and resilience has also been examined in great detail, based on a wide variety of conceptual framings (see, for example, Joakim et al. 2015, Miller et al. 2010, Nelson et al. 2007, Turner 2010, Polsky et al. 2007). However, despite a few commendable attempts at conceptually integrating vulnerability and resilience (see, especially, Joakim et al. 2015), much attention has yet to be paid to the task of operationally combining the two frameworks with a view to supporting adaptation on the ground.

Engle (2011) discusses two reasons why it might be practically useful to combine vulnerability and resilience thinking, allowing one analytical framework to address the shortcomings of the other:

(i) Vulnerability research, which currently takes place within social science disciplines such as Human Geography, Political Ecology, and Development Studies, has become increasingly specialised, detached from natural hazards research, and confined to social vulnerability; interdisciplinary studies focusing on both physical and social aspects of vulnerability are not very common. On the other hand, resilience research, with its origins in Ecology and physical scientific modelling frameworks such as complex systems theory, often engages inadequately with the social dimension of the social-ecological system (SES).

(ii) Vulnerability is generally assessed through actor-focused conceptual frameworks, which are easy to operationalise empirically and generate practitioner-friendly outputs. However, such frameworks generally do not capture processual complexities, and fail to provide a holistic appreciation of how the system works. Instead, they consider how discrete elements of the system function individually. In contrast, resilience frameworks tend to be process-centric and focused on revealing the complex relationships and interactions among the various elements of the coupled SES, but are difficult to put into practice (see Nelson et al. 2007).

Expanding upon Cutter et al.'s (2008) representation of vulnerability and resilience as two intersecting circles, Engle (2011) identifies the intersecting space as adaptive capacity, suggesting that it uniquely links the two concepts. Engle (2011) uses several compelling utilitarian arguments to advocate the use of adaptive capacity assessments for integrating vulnerability and resilience frameworks. Some of them are as follows:

(i) Adaptive capacity is so positioned that human beings can shape and control it, but it affects both human and non-human dimensions of social-ecological systems.

(ii) The concept of adaptive capacity is familiar to both vulnerability and resilience scholars and practitioners, and its emphasis on the institutional, managerial, and governance-related aspects of adaptation makes it appealing to policymakers.

(iii) Resilience has a system-preserving component that may be viewed as a negative (ultimately vulnerability-fostering) property if it resists system-altering or system-dismantling forces that are capable of eliminating vulnerabilities inherent in the system itself (see Walker et al. 2006, 2004). However, adaptive capacity includes only those aspects of a system's capacity to persist that and are compatible with its capacity to undergo modifications or even radical transformations into entirely new entities, thereby fostering resilience while never fostering vulnerability. It is always desirable to enhance adaptive capacity (and there can never be too much of it), because it is a positive system property from both resilience building and vulnerability reduction perspectives.

(iv) Although vulnerability reduction is a favourable outcome for both climate change adaptation and disaster risk reduction (Cardona et al. 2012), assessments based on vulnerability indicators often emphasise the weaknesses of the system, thereby potentially stigmatising or demoralising stakeholders (see also Handmer 2003). Adaptive capacity assessments, on the other hand, highlight the positive aspects of systems and possibilities for building on those strengths. Therefore, seeing the vulnerability reduction challenge through the lens of adaptive capacity is likely to have positive motivational effects on all stakeholders.

In response to Engle's (2011) arguments, this dissertation uses adaptive capacity appraisal as a tool for harmonising vulnerability and resilience thinking. For the harmonisation to be effective, it is necessary to characterise adaptive capacity in such a manner that it overcomes the dualism between the atomistic, actor-focused vulnerability framework and the holistic, system-focused/process-centric resilience framework. Practice theory is increasingly recognised as a source of intellectual resources that entail no primacy for either human agency nor social structure (Reckwitz 2002, Giddens 1984, Bourdieu 1977). As such, it presents itself as a viable medium for such an integrative characterisation of adaptive capacity.

Practice theory arises from a loose collection of diverse 20th-century works by philosophers such as Wittgenstein, social and cultural theorists such as Bordieu, Giddens and Foucault, and science and technology theorists such as Latour (Schatzki et al. 2001). It is essentially an attempt at finding a compromise between methodological individualism (the view that social phenomena are best explained in terms of individual motivations and actions) and methodological holism (the view that social phenomena are best explained in relation to collective, overarching structures and ordering forces) (Postill 2010). This implies that while structures (such as those comprising culture) are seen to become imprinted or internalised as behaviour-guiding dispositions within the human agent, the *practices* or "routinised" behaviours (Reckwitz 2002, p. 249) undertaken by the agent under the influence of those structures are seen to both reproduce the structures and be capable of transforming them (Bourdieu 1977). Therefore, practices are shaped by the system within which they are repeatedly constituted and performed; equally, the repeated constitution and performance of practices shapes the system itself (Ortner 1984).

According to Reckwitz (2002, p. 249), practices encompass the following interconnected elements: "[i] forms of bodily activities, [ii] forms of mental activities, [iii] 'things' and their use, [iv] a background knowledge in the form of understanding, [v] know-how, [vi] states of emotion and motivational knowledge". Simplifying Reckwitz's inventory, Shove et al. (2012) suggest that practices are shaped by interactions among *materials* (comprising iii and i), *competences* (v and iv), and *meanings* (vi and ii). Arguably, these three elements of practices and their interactions broadly cover the same ground as *resources*, *strengths*, and *attributes*, which the IPCC identifies as constituents of adaptive capacity and ingredients of adaptive actions. Adaptation has already been examined as a set of cultural practices (Denevan 1983) and as a set of intersecting processes built around everyday practices (mobility, exchange, rationing, pooling, diversification, intensification, innovation and revitalization: Thornton and Manasfi 2010). The capacity for carrying out such adaptive processes has already been assessed in terms of what could be usefully re-framed as practice-embodying interactions among materials, competences, and meanings (see Kaul and Thornton 2014).

By formally enabling practice thinking to lend shape and substance to adaptive capacity, a conceptual vocabulary could be made available for a practically useful dialogue between vulnerability and resilience. Each practice element could be studied individually as an ingredient of adaptive capacity, which is desirable from the atomistic, actor-focused vulnerability perspective. At the same time, links between practice elements, each of which is a process of interaction, could be examined in relation to the adaptive practice, the entire bundle or complex of adaptive practices, or the entire meta-bundle or meta-complex of adaptive practices that embodies the adaptive capacity of the system (the community interacting with climate-related geohazards in the context of this study). This kind of dynamic, multi-scalar process-centric assessment is desirable from the holistic, system-focused resilience perspective. It is by providing an intellectual medium for uniting these two perspectives that practice theory could provide a deep insight into adaptation. When the focus is on examining adaptive practices in their entirety, analytical primacy may be given neither to the elements of adaptive practices nor to the web of active links among them, neither to individually operating actors nor to the social-environmental system within which they act. This study, therefore, uses a practice-based framing of adaptive capacity to empirically engage with vulnerability and resilience in the field. The empirical insights thus gained feed back into the conceptualisation of adaptive capacity (see Chapter 7), contributing to an attempt at building an integrated vulnerability-resilience framework that can practically support climate change adaptation and disaster reduction.

2.2.3. Towards a holistic strategy for adaptation and risk reduction

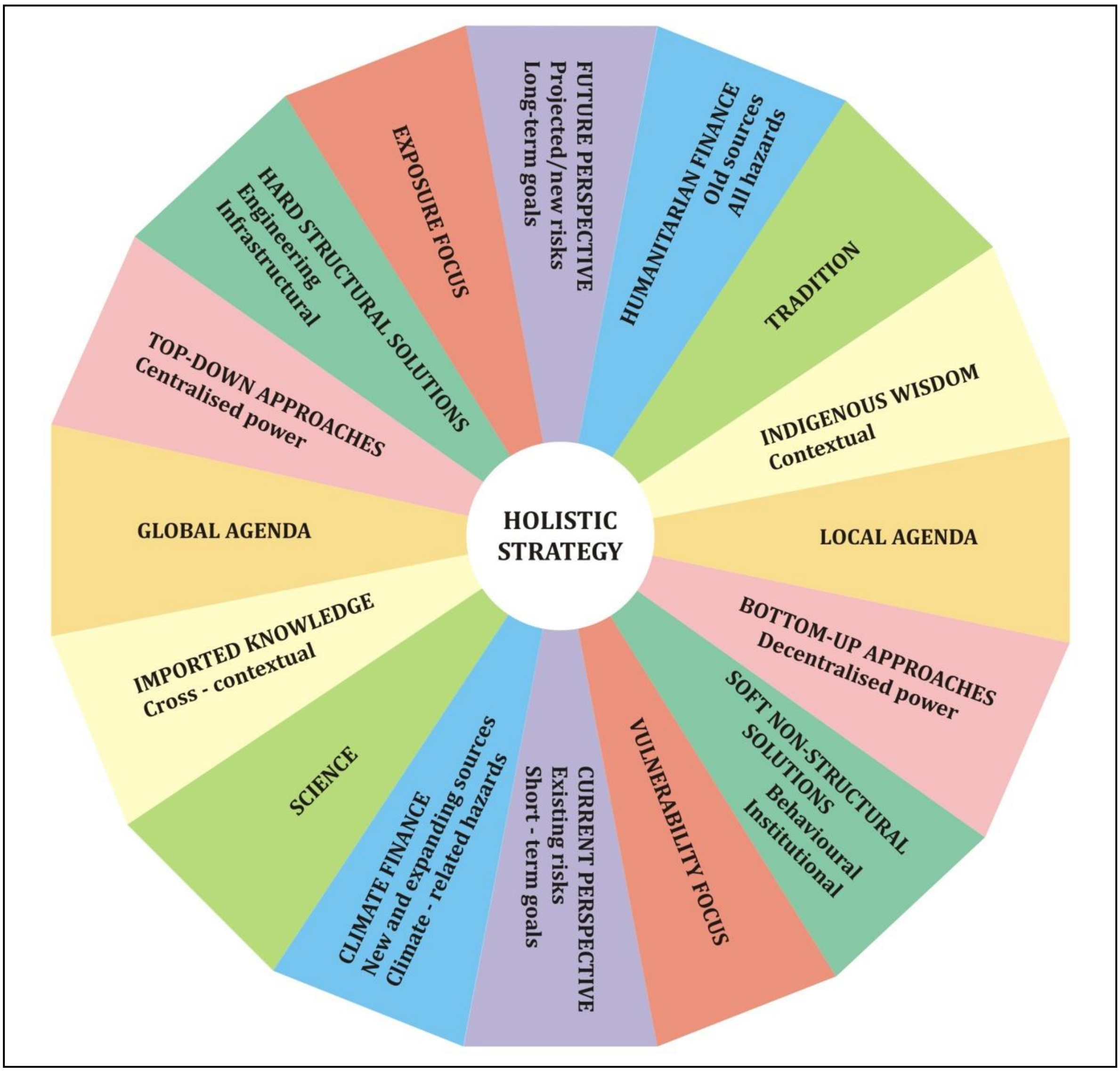
The hydrometeorologically triggered geohazards that this dissertation examines are highly responsive to climate change and affect developing, modernising societies. The task of assessing and managing the human risks associated with these hazards, therefore, lies at the intersection of the academic/policy/practice fields of climate change, disasters, and development. This makes it difficult to comprehensively strengthen the exposed communities' adaptive capacities without coherently linking the distinct, parallel approaches that exist within the boundaries of these overlapping disciplines (see Venton and La Trobe 2008, Thomalla 2006, Schipper et al. 2016, Kelman et al. 2015, Kelman et al. 2016, Kelman 2017, Kaul and Thornton 2014). It is in this context that, apart from bringing together Western scientific and local epistemologies of hazards and connecting the conceptual paradigms of vulnerability and resilience within climate change research, the dissertation more broadly endeavours to advance sustainable development through a combined strategy for climate change adaptation (CCA) and disaster risk reduction (DRR). Kelman et al. (2015, p. 21) make a strong case for this, calling for the integration of CCA into DRR, and of DRR into wider sustainable development processes:

"Climate change is one contributor to disaster risk and one creeping environmental change amongst many, and not necessarily the most prominent or fundamental contributor. Yet climate change has become politically important, yielding an opportunity to highlight and tackle the deep-rooted vulnerability processes that cause "multiple exposure" to multiple threats. To enhance resilience processes that deal with the challenges, a prudent place for climate change would be as a subset within disaster risk reduction. Climate change adaptation therefore becomes one of many processes within disaster risk reduction. In turn, disaster risk reduction should sit within development and sustainability to avoid isolation from topics wider than disaster risk. Integration of the topics in this way moves beyond expressions of vulnerability and resilience towards a vision of disaster risk reduction's future that ends tribalism and separation in order to work together to achieve common goals for humanity."

Admittedly, the analytical approach to environmental risk that the present study adopts is rooted within CCA and the relatively positivist, IPCC-led top-down climate change impacts research culture surrounding it (see Mercer 2010). This is reflected in the importance that the study attaches to internationally driven science-based assessments and modelled projections of current and future hazards, physical exposure to those hazards, and associated impact scenarios. However, the study does actively spread out of the IPCC realm, embracing the more bottom-up, community-based, social vulnerability-focused, livelihood-oriented, and relatively less futuristic perspectives on risk that dominate development studies and DRR research (see Venton and La Trobe 2008).

In order to widen its fundamentally climate change impact-oriented approach to risk, the study draws upon three other schools of thought from environment/development studies. Birkmann et al. (2013) identify these social scientific perspectives on environmental risk as: (i) the *political economy* view, which generally focuses on a social unit's inherent vulnerability (e.g. poverty, food insecurity, lack of livelihood resources) and situates local risk (and often associated power structures and inequalities) within the context of wider political, socio-economic, organisational, and resource governance structures and systems/regimes (e.g. the pressure and release model of risk: Blaikie et al. 1994, Wisner et al. 2003; sustainable livelihood approaches: see DFID 2000, Kollmair and Gamper 2002; political ecology approaches: see Robbins 2012); (ii) the *social-ecology* view, which examines risk in terms of complex webs of relationships and dynamic processes of interaction among social and ecological elements within coupled human-environmental systems (see, for example, Turner et al. 2003); and (iii) the *disaster risk assessment* view, which tends to offer relatively comprehensive and practically oriented (albeit rarely futuristic) engagements with the social, cultural, economic, and managerial dimensions of vulnerability/resilience, while also covering hazard exposure, capacities for response, and feedback loops that demonstrate the dynamic nature of vulnerability/resilience and can be exploited to reduce risk (see, for example, UNISDR 2015, Birkmann 2006, Cardona 2011, Carreño et al. 2007).

Fig. 2.1. An idealised holistic strategy for climate change adaptation and disaster risk reduction (based on Venton and La Trobe 2008, Mercer 2010, Thomalla et al. 2006, IPCC 2012b)



The wheel represents dynamism, which is achieved through iterative learning and innovation.

Source: Reproduced from Kaul (2012)

Bringing together the above social scientific perspectives on risk as well as mainstreaming local/indigenous worldviews through "two-eyed seeing" enables the dissertation to work towards developing a fairly holistic and pragmatic adaptive strategy in the face of climate-related disaster risk (see Fig. 2.1.) Such a strategy would ideally achieve the following:

(i) Engage with both the geophysical component of risk and its social, cultural, economic, political, and institutional/managerial/governance-related dimensions (Birkmann et al. 2013);

(ii) Marry global and national-level CCA and DRR agendas with local aspirations, CCA governance with wider work on sustainable development and livelihood issues, externally formulated policies and schemes with community-based plans, imported cross-contextual knowledge with indigenous context-specific knowledge, engineering-based risk mitigation measures with adaptive behavioural solutions, and modern science with traditional wisdom (Mercer 2010, Venton and La Trobe 2008, Kelman et al. 2015, Schipper et al. 2016);

(iii) Address the complex interplay between underlying environmental and human drivers of risk – for example, interactions among an increasingly extreme precipitation regime, rapid urbanisation, and poverty (UNISDR 2015);

(iv) Promote adaptive practices that are compatible with local cultures and responsive to indigenous understandings of the environment (Schipper et al. 2014, Barnes et al. 2013).

This chapter has provided a multidisciplinary overview of key literatures as well as conceptual, theoretical and epistemological perspectives relevant to the empirical analysis undertaken in the rest of the dissertation. What follows is an account of the methodological framework, along with a brief introduction to the two Himalayan case studies.

3. Methodology

3.1. Introduction

Complex research challenges that involve interactions between people and the environment need to be tackled through innovative, integrative and insightful approaches that overcome the traditional barriers between the natural sciences, social sciences and humanities; between paradigms within these disciplines; and between academic, practitioner and local knowledge (Curtis and Oven 2012, Lane et al. 2011, Mazzocchi 2006; see also Lowe and Phillipson 2009). In attempting to holistically understand and enhance the adaptation of remote communities to precipitation-related geohazards in rapidly changing high-mountain environments, this dissertation adopts such an approach.

The dissertation engages with two case studies, both remote, largely traditional rural communities that inhabit changing high-altitude environments in two different parts of the Himalaya in India – the Upper Lāchen Chú (ULC) Basin in the Eastern Himalayan state of Sikkim and the Upper Mandākinī (UM) Basin in the Western Himalayan state of Uttarakhand (see Figs. 3.1-3.3, Table 3.1 for geographical and social settings). It employs a cross-disciplinary and substantially field-based mixed-methods framework to examine: (i) climate change-related geophysical risks as well as local ontologies, understandings, and cultural constructions thereof, and (ii) communities' appraisals of their own adaptive capacities in the face of those risks. The case study findings are then synthesised to develop a strategic framework for culturally responsive action towards managing disaster risk, supporting climate change adaptation, and making people's livelihoods more resilient in the long run.

The chosen Himalayan case studies are fairly typical examples of far-flung developing-world high-mountain communities that are exposed to multiple, interacting precipitation-triggered geohazards such as earth slides, debris flows, flash floods, and outburst floods from moraine-dammed glacial lakes in deglaciating, tectonically active environments. They were selected for three key reasons. Firstly, they were among the extremely few Himalayan communities that inhabited high-altitude landscapes for which some detailed scientific geohazard assessments were already available. Secondly, the communities were found to be living amidst comparably rapid climatic and socio-economic changes in two geomorphically similar periglacial valleys that were both within the reach of summertime southwest monsoon rainstorms, but were located nearly 1,000 kilometres apart and in two rather different cultural regions – the ethno-religious setting being Tibeto-Burman Buddhist in ULC and Indo-Aryan Hindu in UM. This combination of distinct cultural milieus and similar exposures to climate-related geophysical hazards (operating concurrently with rapid modernisation) offered the opportunity to undertake a cross-cultural comparative study of adaptation and resilience in the face of socio-environmental change and risk. Thirdly, one of the case study communities (UM) had already been ravaged by a precipitation-triggered lake outburst and debris flow disaster (June 2013), which was akin to what the other community (ULC) could potentially face in the near future, considering that it was located directly downstream of a large, precariously moraine-dammed proglacial lake. This situation was expected to facilitate a "before/after"-type comparison between the two communities, allowing the experiences of the already-disaster-affected community to be used to understand and enhance the adaptive capacity of the other community as well. With a view to ensuring comparability between the case studies, the research design used with one community was replicated, to the extent possible, for the other community.

This chapter details and reflects on the research methods and disciplinary perspectives that come together to constitute the project's epistemically varied methodological framework. Table 3.2 provides an overview of individual methods in relation to the specific research questions that they were employed to address.

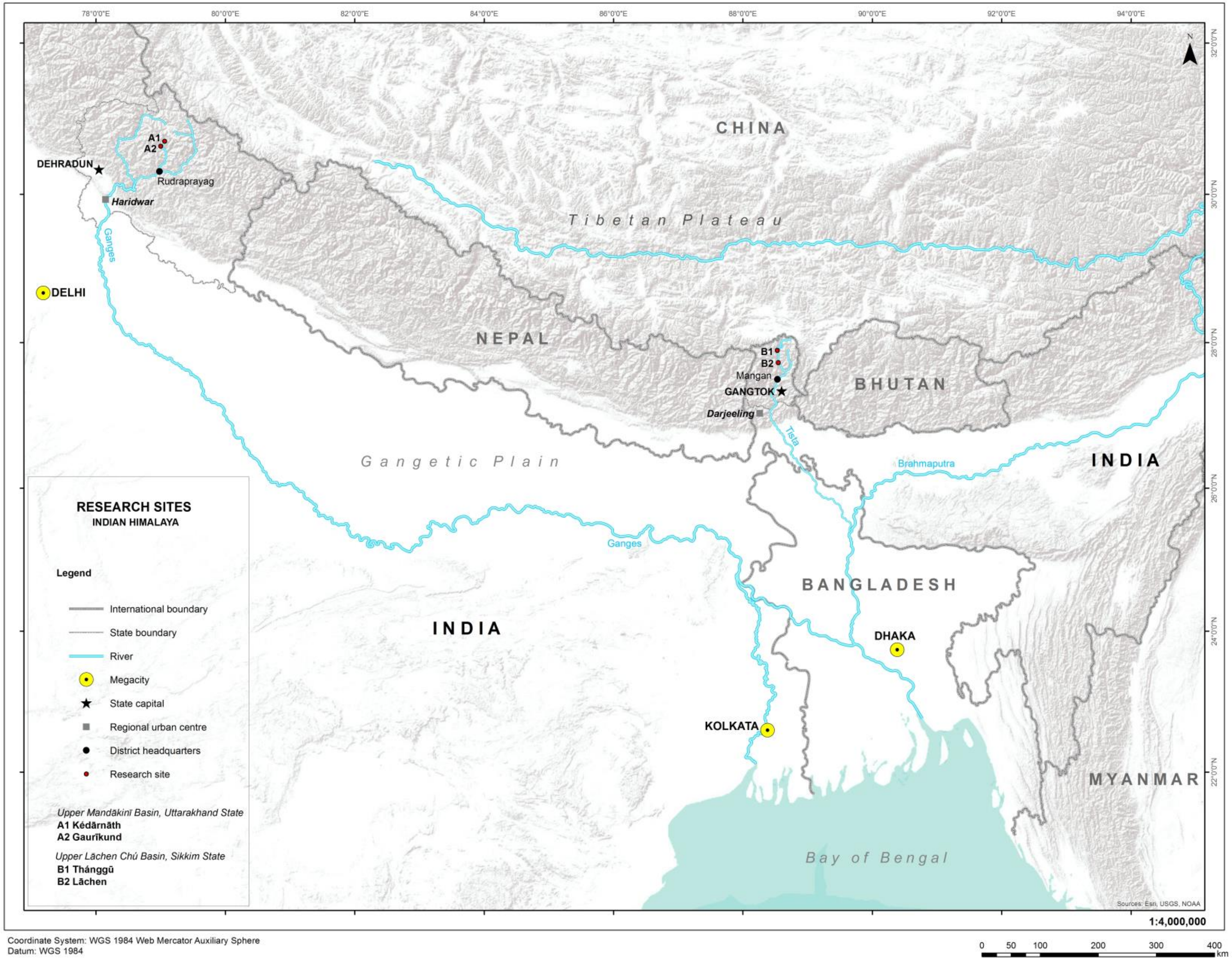


Fig. 3.1. Locations of case study sites in the Indian Himalaya

Fig. 3.2. Locations of the two research sites in the Eastern Himalayan Upper Lāchen Chú (ULC) Basin and the reference meteorological stations at Mangan, Gangtok, and Darjeeling in the wider region

Fig. 3.3. Locations of the four research sites in the Western Himalayan Upper Mandākinī (UM) Basin and the reference meteorological station at Dehradun in the wider region

Table 3.1. Fact sheet on the Upper Lāchen Chú (ULC) and Upper Mandākinī (UM) communities, India

S. No.	Parameter	*Upper Lāchen Chú*	*Upper Mandākinī*
1	**Principal research site** (coordinates, altitude)	Thánggū (27°53'44''N, 88°32'13''E; 3,910 m) (including herders' camps at Byámzé, Minbolung, Dambáché, Nyingmáten, and Phālung in the Jāchú - Lhāshar Chú Valley)	Kédārnāth (30°44'07"N, 79°04'00"E; 3,547 m) (including pilgrims' camps at Lenchaulī and immediately downstream of Kédārnāth in the Upper Mandākinī Valley)
2	**Other settlements** where interviews were conducted (altitudes)	Lāchen (2,700 m)	Gaurīkund (1,994 m) Trijugīnārāyan (2,217 m) Dewalī Bhanigrām (1,169 m)
3	**Local self-government area** Dzumsá/Grām Panchāyat (village council) or Nagar Panchāyat (semi-urban town council)	Lāchen Dzumsá	Kédārnāth Nagar Panchāyat Gaurīkund Grām Panchāyat Trijugīnārāyan Grām Panchāyat Dewalī Bhanigrām Grām Panchāyat
4	**Sub-district and block** (headquarters under Sub-Divisional Magistrate)	Chungtháng (Chungtháng)	Ukhīmath (Ukhīmath)
5	**District** (headquarters under District Magistrate)	North Sikkim (Mangan)	Rudraprayāg (Rudraprayāg)
6	**State/province (capital)**	Sikkim (Gangtok)	Uttarakhand (Dehradun)
7	**Nearest city** with a population of >100,000 (travel distance and time, assuming no road blockages due to landslides)	Gangtok (156 km / 8-hour drive to Thánggū)	Rishikesh (208 km / 9-10 hour-drive to Gaurīkund + 16 km / 5-8-hour trek to Kédārnāth)
8	**Geographical region / river basin**	Eastern Himalaya / Brahmaputra Basin	Western Himalaya / Ganges Basin
9	**Climate type**[A] (Köppen-Geiger classification: see Kottek et al. 2006) **/ / Vegetation type**	*Thánggū* Dwc*: Monsoon-affected sub-arctic climate with cool, wet summer and cold, relatively dry winter; winter drier than in Kédārnāth owing to a weaker influence of snow-bearing extratropical westerly low pressure systems originating over the Mediterranean region / / Forest-tundra ecotone	*Kédārnāth* Dwc*, but nearly Dfc^: Monsoon-affected sub-arctic climate with cool, wet summer and cold, relatively less humid winter; winter considerably wetter than in Thánggū, owing to a stronger influence of snow-bearing extratropical westerly low pressure systems originating over the Mediterranean region // Alpine meadow
10	**Approximate summertime (May-October) civilian population**	*Thánggū and around*[B] ~180-420 *Lāchen*[C] 1,325 (589 females, 736 males)	*Kédārnāth* Locals[C]: 612 (3 females, 609 males); Immigrant workers*: ~100-300; Resident pilgrims on any given day (May-October)[B]: ~250-3,000 *Gaurīkund* Locals[C]: 223 (87 females, 136 males); Immigrant workers*: ~150-500; Resident pilgrims on any given day (May-October)[B]: ~250-5,000 *Trijugīnārāyan* Locals[C]: 1,360 (667 females, 693 males) *Dewalī Bhanigrām* Locals[C]: 1,188 (589 females, 599 males prior to male-only disaster fatalities in 2013)

11	**Number of households**[C]	Thánggū and around: 63 Lāchen: 338	Kédārnāth: 297, Gaurīkund: 43 Trijugīnārāyan: 235 Dewalī Bhanigrām: 248
11	**Mean household size**[D] (persons)	4.2	5.1
12	**Mean land holding area per household**[D] (hectares)	1.3	0.4
13	**Mean annual income per capita**[D] (nominal, Indian Rupees / US Dollars[E])	INR 201,580 USD 2,879	INR 128,776 USD 1,840
14	**Principal ethnic groups**	Bhutiā (Lāchenpā) Dokpā	Garhwāli (mostly Brahmin caste) Népālī (immigrant Nepalese nationals)
15	**Proportions of Scheduled Tribes (ST) and Scheduled Castes (SC)**[F] **in interview sample**	ST: 100% SC: 0%	ST: 0% SC: 7%
16	**Principal languages**	*Bhutiā or Sikkimese Tibetan* (Dzongkha-Lhokā[G] sub-division of Tibetic cluster of Tibeto-Burman group of Sino-Tibetan language family) *Dokpā* (Ü-Tsang[G] or Central Tibetan subdivision of Tibetic cluster of Tibeto-Burman group of Tibeto-Burman language family) *Népālī* (Eastern Pahārī[G] sub-division of Indo-Aryan group of Indo-European language family, lingua franca across Sikkim) Local official languages: *Bhutiā, Népālī, English*	*Hindī/Hindostānī* (Indo-Aryan group of Indo-European language family, lingua franca across Uttarakhand) *Garhwāli* (Central Pahārī[G] sub-division of Indo-Aryan group of Indo-European language family) *Népālī* (Eastern Pahārī[G] sub-division of Indo-Aryan group of Indo-European language family) Local official languages: *Hindī, English*
17	**Dominant religious beliefs**	Tibetan Vajrayāna Buddhism (Nyingmā tradition with animist elements)	Western Himalayan Hinduism (Shaiva tradition with an emphasis on Ādi Shankara's Advaita doctrine)
18	**Principal occupations**	Livestock rearing (mainly yak and dzo/cow-yak hybrid), crop farming (potato, radish, buckwheat), small and micro enterprises (including tourism-related hotels and lodges, tea shops, kiosks, taxi services), construction work	Priestly services (males only), small and micro enterprises (including pilgrimage tourism-related lodges, tea shops, kiosks, taxi services), farming (crops: wheat, barley, maize, rice, lentils, vegetables, fruits; animals: mainly cattle but also sheep and goats), portering, muleteering, construction work

[A] Approximate climate profiling based on 1982-2012 climate-data.org climate model datasets for Lachung, Katao, Yumesamdong,Kedarnath as well as local and regional climate data from Telwala et al. (2013), Dobhal et al. (2013), and Kaul and Thornton (2014)
* Dwc climate conditions: Mean temperature of coldest month below −3 °C and 1–3 months with mean temperature of 10 °C or higher; at least 10 times as much precipitation in the wettest summer month (July) as in the driest winter month (November)
^Dfc climate conditions: Mean temperature of coldest month below −3 °C and 1–3 months with mean temperature of 10 °C or higher; precipitation regime without significant seasonal differences in that *neither* of the following conditions is satisfied: (i) at least 3 times as much precipitation in the wettest winter month as in the driest summer month (which receives <30 mm precipitation); (ii) at least 10 times as much precipitation in the wettest summer month as in the driest winter month.
[B] 2015-2016 field data
[C] 2011 government census data
[D] Based on interview sample (n = 30)
[E] Currency exchange rate: 1 US Dollar (USD) = 70 Indian Rupees (INR)
[F] Officially designated social groups that were historically oppressed or disadvantaged and currently benefit from positive discrimination (quotas in state education, employment, and political representation) as per the Indian constitution
[G] See Tournadre (2005), Masica (1991, pp. 9-14)

Table 3.2. Overview of research methods

<table>
<tr><th rowspan="3">Research questions</th><th colspan="6">Research methods</th></tr>
<tr><th colspan="2">Climatology (Earth Science)</th><th colspan="2">Geomorphology (Earth Science)</th><th colspan="2">Human Geography (Social Science)</th></tr>
<tr><th>Review of published climatological work</th><th>Primary quantitative analysis</th><th>Review of published geohazard studies</th><th>Primary geospatial analysis</th><th>Ethnographic work</th><th>Other qualitative work</th></tr>
<tr><td>1. How do local understandings (traditional or otherwise) of climatic change, hydro-meteorological extremes, and associated high-mountain geohazards compare with regional- and local-scale Western scientific understandings?</td><td>Regional-scale observed trends in temperature, precipitation, and their extremes since the mid-20th century

Regional and sub-regional gridded multi-model ensemble projections of temperature as well as precipitation and its extremes for the late 21st century</td><td>Local-scale trends in 17 indices of precipitation and its extremes (with special reference to the summer monsoon season) as well as changes in precipitation variability over the past few decades, all based on daily precipitation data (spanning up to 114 years) from meteorological stations located in the same regions as the research sites</td><td>Geohazard impact scenarios based on fluid dynamics and sediment transport simulation modelling

Geomorphological reconstructions of previous rainfall-triggered disasters</td><td>Terrain and geohazard mapping (at scales of 1:10,000 to 1:100,000) based on digital elevation models (derived from ASTER and Google Earth data) and ground-based GPS- and camera-aided qualitative geomorphological surveys</td><td rowspan="2">In-depth semi-structured interviews (total sample size: 60 = 30 interviews x 2 communities, average interview duration: 132 minutes)

Participant observation (involving participation in a range of everyday activities for several weeks)</td><td>Participatory mapping exercises exploring the communities' spatialised conceptions of the physical landscape and the geohazards present in it

Exploratory focus group discussion (FGD) to develop a preliminary understanding of the socio-environmental setting prior to ethnographic work with each community</td></tr>
<tr><td>2. How do local communities construct and appraise their own adaptive capacities in the face of risks from climate change-related high-mountain geohazards and concurrent social change?</td><td colspan="4">Review of Earth Science empirical findings</td><td>FGD with community elites such as members of the elected village-level self-government body; FGD (female-only) with members of a women's collective

Elite interviews with public administrators at district, state, and national levels of government

Review of legislative/plan documents</td></tr>
<tr><td>3. How can community-level climate change adaptation and disaster reduction practically benefit from holistic, grounded, and culturally responsive engagements with risk?</td><td colspan="4">Review and synthesis of Earth Science empirical findings</td><td colspan="2">Review and synthesis of Social Science empirical work

Strategic planning using a community SOA (Strengths, Opportunities, Aspirations) analysis based on a practice-based characterisation of adaptive capacity in the proposed AdapT conceptual model</td></tr>
</table>

3.2. Earth science methods

The first research question of the study relates to a comparison of Western scientific and community knowledges of climatic change, precipitation extremes, and associated geohazards. Addressing it necessitated some engagement with earth science data, largely secondary but also primary, with a view to establishing a firm and fairly rigorous Western scientific knowledge base that could be used to contextualise the rich ethnographic data on local understandings (see Chapters 4 and 5). This included reviews of relevant published regional- and local-scale earth science studies, both spatial and non-spatial, as well as some intensive first-hand quantitative climatological data analysis, qualitative geomorphological surveying, and basic terrain mapping.

3.2.1. Climatic change assessment

3.2.1.1. Review of published work

Published regional temperature and precipitation change assessments for the past half century were compiled and reviewed for comparison with community insights from both research sites – the Eastern Himalayan ULC Basin and the Western Himalayan UM Basin. The reviewed studies were based largely on observational datasets assembled by the China Meteorological Administration, the India Meteorological Department, and the Climate Research Unit, UK.

Published regional and sub-regional gridded multi-model ensemble projections of temperature and precipitation for the mid- and late 21st century were also reviewed. These climate modelling studies were based largely on the UK Met Office Hadley Centre's regional climate modelling system Providing REgional Climates for Impact Studies (PRECIS) as well as the World Climate Research Programme's Coupled Model Intercomparison Project Phase 5 (CMIP5) and Coordinated Regional Climate Downscaling Experiment (CORDEX).

3.2.1.2. Primary quantitative climatological analysis

With a view to positioning the local communities' in-depth qualitative observations of precipitation change in relation to Western scientific observations, detailed first-hand quantitative climatological analyses were conducted for both study regions to determine whether any significant changes in precipitation and its extremes had occurred over the past several decades. These analyses specifically considered hydrometeorological extremes during the June-September summer monsoon rainy season, which are associated with a wide range of slope- and flooding-related hazards in Himalayan environments. Daily observed precipitation data (spanning between 15 and 114 years) from government-operated weather stations in the same regions as the two research sites were obtained via the National Data Centre (NDC) of the India Meteorological Department (IMD).

Drawing upon the core climate change indices recommended by the Expert Team on Climate Change Detection and Indices (ETCCDI 2009, Peterson et al. 2001, Karl et al. 1999), the following indices of precipitation and its extremes were used to analyse the daily data with special reference to the June-September monsoon season and its individual months. The trends observed in these indices were then compared with qualitative community observations of corresponding climatic changes over the past few decades:

(i) Total monthly/seasonal precipitation (mm)
(ii) Wet days (number of days in the month/season with precipitation ≥1mm)
(iii) Mean daily precipitation intensity (total monthly/seasonal precipitation divided by the number of wet days; mm day^{-1})
(iv) Maximum one-day precipitation (highest daily precipitation value recorded in the month/season; mm)
(v) Maximum three-day precipitation (maximum precipitation recorded over three consecutive wet days in the month/season; mm)
(vi) Maximum five-day precipitation (maximum precipitation recorded over five consecutive wet days in the month/season; mm)
(vii) Maximum wet spell length (maximum number of consecutive wet days in the month/season)
(viii) Mean wet spell length (average number of consecutive wet days in the month/season)
(ix) Total precipitation during the longest wet spell (mm)
(x) Number of days with precipitation equalling or exceeding the 80th percentile of daily precipitation in the month/season
(xi) Number of days with precipitation equalling or exceeding the 90th percentile of daily precipitation in the month/season
(xii) Number of days with precipitation equalling or exceeding the 95th percentile of daily precipitation in the month/season
(xiii) Number of days with precipitation equalling or exceeding the 99th percentile of daily precipitation in the month/season
(xiv) Total precipitation received in the month/season as daily amounts equalling or exceeding the 80th percentile (mm)
(xv) Total precipitation received in the month/season as daily amounts equalling or exceeding the 90th percentile (mm)
(xvi) Total precipitation received in the month/season as daily amounts equalling or exceeding the 95th percentile (mm)
(xvii) Total precipitation received in the month/season as daily amounts equalling or exceeding the 99th percentile (mm)

In view of their non-normal distributions (owing to large numbers of extreme values) as well as the presence of significant numbers of missing values, the daily precipitation datasets were subjected to the non-parametric (distribution-free) Mann-Kendall test (as opposed to parametric linear regression analysis) in order to determine whether a monotonic increasing or decreasing trend was present for each of the above indices over the past few decades (Mann 1945, Kendall 1975; see Gilbert 1987, pp. 208-217). The true slope of the linear trend for each precipitation index was estimated using the non-parametric Theil-Sen estimator, which, in comparison with the ordinary least squares estimate of slope in parametric linear regression analysis, is insensitive to outliers (extreme values) and was therefore significantly more robust vis-à-vis the skewed distributions of the daily precipitation datasets. The insensitivity of the Theil-Sen estimator of slope to outliers stems from the fact that it is calculated as the median (rather than the outlier-sensitive mean) of the slopes determined by all the pairs of points present in the dataset (Theil 1950, Sen 1968; see Gilbert 1987, pp. 2017-219; see also Hollander and Wolfe 1973, p. 205). The data were processed entirely on Microsoft Excel, and the template application MAKESENS (MAnn-KEndall test for trend and SEN'S slope estimate), developed at the Finnish Meteorological Institute (Salmi et al. 2002), was used to execute the above non-parametric statistical analyses on Microsoft Excel.

For the Eastern Himalayan ULC community, daily precipitation datasets from three regional IMD meteorological stations were analysed – Darjeeling (99-year observational period: 1901-1999), Gangtok (30-year observational period: 1985-2014), and Mangan (15-year observational period: 2001-2015). Their locations relative to the ULC community's Thánggū and Lāchen villages are shown in Fig. 3.2, and their aerial distances and elevational differences from the two villages are given in Table 3.3. Darjeeling is the region's oldest meteorological station and largest town. Since the NDC could not provide data from Darjeeling for the period after 1999, shorter datasets from the more recently established stations at Gangtok, the capital of the ULC community's Sikkim province, and Mangan, the headquarters of the ULC community's North Sikkim district, were also used to cover recent decades. Mangan and Gangtok are the two nearest full-fledged weather stations to the ULC community.

For the Western Himalayan UM community, a single daily precipitation dataset, spanning 114 years (1901-2014), was analysed. This was from Dehradun, the region's oldest meteorological station and the capital of the UM community's Uttarakhand province. Dehradun's location relative to the UM community's Kédārnāth, Gaurīkund, Trijugīnārāyan, and Dewalī Bhanigrām settlements are shown in Fig. 3.3, and its aerial distances and elevational differences from those settlements are given in Table 3.3.

Table 3.3. Aerial distances and altitudinal differences between research sites and meteorological stations

Research site	Reference meteorological station		
Community settlement (altitude)	*Station settlement (elevation)*	*Aerial distance from research site (km)*	*Altitudinal difference from research site (m)*
Upper Lāchen Chú (ULC) Basin Eastern Himalaya			
Thánggū (3,910 m)	Darjeeling (2,112 m)	97	1,798
	Gangtok (1,787 m)	62	2,123
	Mangan (1,189 m)	43	2,721
Lāchen (2,700 m)	Darjeeling (2,112 m)	80	588
	Gangtok (1,787 m)	43	913
	Mangan (1,189 m)	25	1,511
Upper Mandākinī (UM) Basin Western Himalaya			
Kédārnāth (3,547 m)	Dehradun (627 m)	108	2,830
Gaurīkund (1,994 m)		100	1,367
Trijugīnārāyan (2,217 m)		96	1,590
Dewalī Bhanigrām (1,169 m)		101	542

In addition, each of the multi-decadal daily precipitation datasets (Darjeeling, 1901-1999; Gangtok, 1985-2014; and Dehradun, 1901-2014) was partitioned into two or three shorter periods, which were then compared to detect, especially for the summer monsoon season, any significant changes in mean precipitation amount, intensity, and variability between those periods. In particular, inter-period shifts in precipitation variability (determined by the coefficient of variation - the ratio of the standard deviation of precipitation in a certain period to the mean of precipitation for the same period) were compared with any corresponding qualitative community observations.

3.2.2. Geohazard assessment

The few available local- and regional-scale published quantitative geophysical assessments of precipitation-triggered glacial and periglacial slope- and flooding-related hazards in both the ULC and UM valleys were reviewed, so that the local communities' qualitative (often folkloristically rooted) understandings of those hazards could be put into the context of geomorphology. In addition, extensive ground-based qualitative geomorphological surveys were conducted on foot in both study regions, using a handheld GPS device (Garmin eTrex) and an ultra-zoom bridge camera (Nikon Coolpix P510) to record significant terrain features, multiple interacting geohazards, and exposed human assets. Aided by the GPS data and field photographs, high-resolution Google Earth satellite imagery was used to make rapid qualitative multi-hazard appraisals. In order to spatially contextualise both local appraisals and existing Western scientific assessments of geohazards, remote sensing-derived digital terrain data and GPS-derived ground feature mapping data from both sets of field sites were combined in a GIS environment (ESRI ArcGIS) to generate simple geomorphological maps at scales ranging from 1:100,000 to 10,000.

The 1:100,000 terrain overview maps for both study regions were based on digital elevation models with spatial resolutions of 30 metres, which were downloaded free of cost from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM). For the more detailed, larger-scale (1:140,000-1:10,000) geomorphological maps, digital terrain data were extracted from Google Earth at spatial resolutions roughly equivalent to about 2.5 metres using an unconventional and somewhat rough-and-ready but free and fairly reliable method (see Rusli et al. 2014). This involved: (i) digitising at least 400 points over every 1 km x 1 km patch of the relevant coverage areas for the two study regions on Google Earth; (ii) saving those points as KML files and importing them into a freely available web-based geospatial file format conversion tool known as TCX converter; (iii) processing the imported point data to automatically add the correct elevation values that correspond to each set of coordinates; (iv) exporting the latitude, longitude and elevation values for all terrain data points as a CSV file; (v) importing the CSV file into ArcGIS; projecting the point data in ArcGIS and converting them to the Shapefile format; and finally (vi) using the Spatial Analyst Tools in ArcGIS to interpolate the point elevation data to a raster elevational surface by the kriging method and to then generate contours.

For the practical purpose of disaster reduction and community adaptation, highly localised (hamlet-scale) multi-hazard assessments (see Glade et al. 2012) are ideal; it is hardly useful to work with a spatial scale (such as 1:100,000) at which an entire community appears as a dot on a printed map. Unfortunately, adequately fine-scale geotechnical assessments were not available for most hazards in either of the study regions. Given the temporal and financial constraints of the study, nor was it possible to acquire or generate sufficiently detailed input datasets (e.g. large-scale geological and soil maps; digital elevation models with spatial resolutions of 5 metres or higher; remote sensing-based high-resolution land cover and precipitation data) for technically sophisticated process-based quantitative multi-hazard risk modelling at a practically helpful spatial scale that would offer a zoomed-in view of each single settlement. Therefore, the study adopted a largely qualitative, rough-and-ready approach to scientifically assessing multiple interacting geohazards, relying considerably on grounded judgement based on field experience and prioritising practical effectiveness over analytical refinement (see Oven 2009, Oven et al. 2008). If highly localised multi-hazard assessments are to be made available for disaster reduction across large regions (e.g. entire provinces) that span hundreds or thousands of individual settlements, such a pragmatic approach may be indispensable in view of the severe resource constraints and geotechnical database insufficiencies faced by governmental planning agencies in the Global South.

3.3. Social science methods

All of the research questions demanded extensive engagements with qualitative social scientific data. The methods ranged from ethnographic interviews and participatory exercises with communities in the field to reviews of government policy and strategic planning at the desk.

3.3.1. Ethnographic fieldwork: Community interviews and participant observation

A core objective of the study was to gain a deep insight into people's everyday experiences and understandings of environmental changes and hazards, and their own vulnerability, resilience, and adaptive capacity vis-à-vis those changes and hazards. This objective could not have been met with a research tool that mechanically recorded information; a holistic, intensive, and nuanced dialogue was needed to bring out complex meanings (Kvale 1996, Mason 2002a, b). Therefore, I (the researcher) lived and actively engaged with members of each case study community for nine weeks to address three questions: (i) What do they make of the changes that have taken place in their climate and physical landscape over the past few decades? (ii) How do they understand and psycho-culturally relate to any geophysical hazards and risks that may be associated with those environmental changes in the wider context of concurrent social changes? (iii) How do they construct and appraise their own adaptive capacities in the face of risk? For this purpose, I conducted qualitative, in-depth semi-structured interviews with 30 members of each community (see Appendix 2A for a broad interview schedule/outline). Sampling was purposive, and efforts were made to obtain representation across hazard exposure types, livelihood types, social groups, and genders.

Interviews were used in conjunction with participant observation of the everyday cultural practices (at the individual, household, and community levels) that constitute the ways of life in the study areas (Atkinson and Hammersley 1994). The findings of these ethnographic engagements are discussed throughout Chapters 4, 5, and 6.

Prior to being recruited, all research participants were first informally briefed about the project and then made to read or hear the contents of local-language project information sheets and consent forms (Népālī for the ULC community and Hindī for the UM community; see Appendix 3). Their informed consent was either audio-recorded or received as a signature or thumb impression on the consent form. The interviews themselves were audio-recorded and then transcribed. Although 10 of the 30 interviewees in ULC and 12 of the 30 in UM did not request to be made anonymous, all interview data were anonymised and it was ensured that all names of research participants appearing in the dissertation were pseudonyms. This was done in the interest of the interviewees' privacy and safety, especially in relation to remarks that were of a deeply personal or psychological nature, critical of governmental authorities, potentially offensive, or indicative of bigotry.

3.3.1.1. Ethnographic encounters in the Upper Lāchen Chú (ULC) valley

I undertook immersive ethnographic fieldwork in and around the high-altitude hamlet of Thánggū and the larger downstream settlement of Lāchen in the Eastern Himalayan valley of the Upper Lāchen Chú River from October until December 2015. Over two 32-day periods separated by a 10-day break, I conducted 30 interviews in the Népālī and Hindī languages (occasionally mixed with Bhutiā phrases and sentences), each between two and six hours long. I closely observed everyday community life, including activities such as yak herding, local taxi drives, storytelling by community elders, monastic ritual performances, religious excursions, cooking, and communal eating and drinking, despite my inability to accept any food or drink from households that could not be locally verified as safe vis-à-vis the obscure practice of ritual poisoning for the satiation of the wrathful Tibetan goddess Pandenlhāmo's bloodlust. I maintained detailed place-centred ethnographic field notes in English with occasional footnotes and annotations in Népālī and Hindī. An edited excerpt from my field research diary, containing my first impressions of Thánggū, is presented below to give the reader a situated sense of the ULC community and landscape:

> This morning I woke up shivering. My quilt was covered in snow, and so was the bedroom floor. The improvised polythene-bag windowpanes had been ripped apart by the piercing wind. My solar lantern was out of power, but luckily the snow-glow had made the incipient twilight bright enough to show me the way to the kitchen downstairs, where the middle-aged lodge owner Pembā [name changed] had already started to cook salty, oily yak milk tea and instant Maggi noodles on his enormous wood-burning stove. "The polythene must have been blown off?" he asked blithely while plucking two shrivelled wads of yak meat off a garland hanging from the crumbling ceiling. "Yes, and there is snow in the room… I am freezing!" I replied in a very grim tone. "Sit down, my friend, and enjoy a cup of Pembā Special!" Pembā exclaimed mischievously as he poured equal quantities of yak tea and rum into my mug.

It is now midday on 16 October 2015, and a faint, haloed sun is beginning to emerge from behind the low snow clouds. Hundreds of multihued Buddhist prayer flags are fluttering in the wind like butterflies – a very welcome contrast to the bleak white landscape. I am in in the sprawling valley of Thánggū (lit. 'flat space') in India's majestic Sikkim Himālaya, nearly 4,000 metres above the sultry plains of Bengal and not far from the frigid, arid plateau of Tibet. This is the first snow of the season, and it has come very early. It will ultimately nourish the River Tīstā, a major tributary of the mighty Brahmaputra, two of whose many icy headstreams unite right here. The smaller of the two, Jāchú or Lhāshar Chú, flows southwestwards through the heart of the hamlet of Thánggū. It is fed by three sacred bodies of glacial meltwater - Shāká Cho (the most voluminous), Youlhá Khángtsá (three small ponds), and Shärabū Cho, which lie along the southwestern flanks of the deeply glacierised and deified giant that is the Khángchengyáo Mountain. The larger river is known as Lāchen Chú, after Lā-chen (lit. 'big pass'), a much larger village located some 30 kilometres downstream in the same valley, but at a safe height above the riverbed. It stems from the extensive proglacial lake Khángchung Cho, which sits along the western foot of another lofty snow-clad mountain, Pauhunrī. It initially flows west, receiving glacial meltwaters from the northeastern flanks of Khángchengyáo via the large, deep and sacred Cho Lhāmú and Gurudongmār lakes. The river then bends southwards to arrive at the lower edge of Thánggū, where it is joined by the Jāchú.

I had planned for today a long trek up the Jāchú to the 5,000-metre-high, precariously moraine-dammed proglacial lake of Shāká Cho, but that must wait until the sky is blue again. Nonetheless, I have been able to walk around the now-snowbound settlement of Thánggū, and am gradually beginning to feel at ease with local families of Lāchenpā (ethnic Sikkimese Bhutiā agro-pastoralists from Lāchen) and Dokpā (traditionally nomadic ethnic Tibetan high-plateau transhumant pastoralists), whose general opinion of "Delhi-Bombay types" (city dwellers) like me sounds rather unfavourable. Most people seem drowsy and have not left their warm kitchens since breakfast. Pembā's stove is the largest, so there are more people in his kitchen than anywhere else. "Keep your yak calves and grandchildren warm – you don't want them to die of pneumonia!" warns an elderly woman who has decided to leave for Lāchen as soon as the Army has the snow ploughed away. All the dozen heads around the stove nod in agreement. Urging me to join in, Pembā pulls out another yak-hair-topped stool from under his quilt stack and ceremoniously opens another bottle of rum. His young nephew, who is already tipsy, chuckles and then bursts into song. I am amused. Pembā offers a full explanation:

> *"Almost nothing happens here in the winter… just eating, drinking, talking, singing, clearing the snow, praying, and sleeping. Most of us are Lāchenpā, so we slowly go down to our homes in Lāchen between October and December and come back to the pastures around Thánggū between March and May. The Tibetan-speaking Dokpā, along with most of our yaks, move up… yes, they move up, not down, for the winter… to the high, dry-aired, windy, and therefore far less snowy rangelands of Mugūtháng, Gurudongmār and Cho Lhāmú near the Chinese border. Fewer than ten local residents – just two or three households – remain in Thánggū through the winter. But the military camps remain functional, of course. We graze yaks and cattle and grow some food between early May and late September. All our pastures in the Lhāshar Chú Valley, including Byámzay, Minbólung, Dambáché, Nyimāten, Phālung and the ones just below the blessed waters of Shāká Cho, are snow-free and quite green by June… That's a lovely time of year, the season of brotherly love between the Dokpā and us… And we get many tourists in the warm summer vacation months before the rains [May and June]… and then, of course, in this cool and dry Hindu festive season after the rains [October and November]. Tourists prefer to spend their night in Lāchen, but they always halt here for tea and snacks on their way up to our sacred Gurudongmār Lake."*

The local population of the ULC valley comprises a remote, fundamentally agro-pastoral (but seasonally tourism-centred and increasingly mercantile) Bhutiā-speaking Nyingmā-order Vajrayāna Buddhist Lāchenpā community [a few thousand persons altogether, including a couple of ethnic Népālī Hindu spouses]; a small yak-herding, Tibetan-speaking Vajrayāna Buddhist Dokpā community [fewer than a couple of hundred persons altogether]; a sizeable but socially unassimilated Hindu immigrant worker community (road construction workers and other manual labourers employed for a few months) mainly from Indian lowland regions such as Bihār, Bengal and Assam, but also from mountainous Nepal and the ethnic Népālī-dominated southern and western parts of Sikkim [several hundred persons altogether]. Besides, there are the camps of the Indian Army and the specialist high-mountain paramilitary force Indo-Tibetan Border Police (ITBP), about whose populations it is not possible to comment.

From the above population, I interviewed 30 local residents (see Table 3.4 for demographic details). The sampling design was purposive. An effort was made to engage with people from across the several close-knit and often like-minded social circles within the ULC community, while also ensuring that dwelling clusters with high levels of exposure to flooding- and slope-related geohazards were adequately represented, and that the sample reflected the ethnic, occupational and income-related diversities present in the population. However, the combination of my male gender, young age, non-native apparent ethnicity and limited Bhutiā-language vocabulary constrained my access to female experiences, which constituted only about a quarter of all interviews (8 of 30). Male family members present during initial interactions with prospective non-elderly female interviewees tended to implicitly or explicitly express unease about such interactions, compelling me to abort those conversations in the interest of propriety. Interviews with elderly women, who tended not to have attended school and were therefore not fluent in Népālī or Hindī, were particularly challenging owing to "conversation hijacks" by self-appointed interpreters and dominant male members of the household.

The selected sample of 30 included: 14 Lāchenpā (11 men and 3 women) who are seasonal members of 13 (21%) of the 63 households in Thánggū and nearby hamlets and herders' camps as well as permanent members of 11 (3.3%) of the 338 households in down-valley Lāchen; (ii) 5 Dokpā (4 men and 1 woman) who are seasonal members of 4 (6%) of all the 63 households in Thánggū and nearby hamlets and herders' camps as well as permanent members of 4 of the 7 households (yak herds) in up-valley Mugūtháng; (iii) 11 Lāchenpā (7 men and 4 women) who visit Thánggū only occasionally and are permanent members of 10 (3%) of the 338 households in Lāchen. In addition to the 30 main interviewees, 5 male ethnic lowlander construction workers were informally interviewed only about risks associated with rainfall-triggered landslides and flash flooding at four different roadside locations between Lāchen and the end of the civilian road in Gurudongmār.

All Lāchenpā interviewees were members of the *dzumsá*, a traditional local self-government institution (for Lāchen, Thánggū, and all intervening villages), whose democratically elected, legally potent, and socially well-regarded all-male governing council comprises two equally powerful chiefs known as *pipon*, five or six advisors known as *gyämbo,* two treasurers known as *tsēpo,* and one nominated adjutant or *gyápen* for each *pipon.* There is also a separate governing body for ecclesiastical affairs, headed by the *chothimpā,* the most senior *lāmā* (Buddhist monastic teacher) in the village. I had regular discussions with both these groups of male community élites as well as one with a mixed-age group of female weavers and housewives at the government-run handicrafts and handloom centre in Lāchen.

As regards access to the ULC community, I discovered that most interviewees held strong preconceived notions about my identity and socio-moral background, which mildly persisted even after a clear declaration of the purpose of my visit as part of the informed consent process. Listed below are the five impressions about me that were the most conspicuous: (i) “uncouth, materialistic city-dwelling North Indian lowlander who should be kept away from our girls”; (ii) “pampered relative of an Indian Army major or colonel”; (iii) “exotic, adventurous European backpacker eager to embrace local customs”; (iv) “respectable-looking Indian émigré scholar” [somewhat correct]; and (v) “élite government official, scientist or engineer from Gangtok [the provincial capital], Kolkata or New Delhi”. While the first one limited access to the experiences of young female community members, perhaps the last three favourably influenced the quality of the acquired ethnographic data.

Table 3.4. Upper Lāchen Chú (ULC) community: Demographic profile of interviewees

S. No.	Parameter	Number of interviewees								
		Thánggū (and herders' camps)			Lāchen			**All settlements**		
		F*	M	T	F	M	T	**Female**	**Male**	**Total**
1	**Sample size**	4	15	19	4	7	11	**8**	**22**	**30**
2	**Age** (sample median: 57.5 years)									
	18-50 years	1	3	4	1	5	6	**2**	**8**	**10**
	Over 50 years	3	12	15	3	2	5	**6**	**14**	**20**
3	**Ethnicity**									
	Lāchenpā	3	11	14	4	7	11	**7**	**18**	**25**
	Dokpā	1	4	5	0	0	0	**1**	**4**	**5**
4	**Annual income per capita^**									
	Low *< INR 125,000* *< USD 1,786*	2	7	9	2	2	4	**4**	**9**	**13**
	Medium *INR 125,000-225,000* *USD 1,786-3,214*	2	5	7	1	2	3	**3**	**7**	**10**
	High *> INR 225,000* *> USD 3,214*	0	3	3	1	3	4	**1**	**6**	**7**
5	**Principal occupation**									
	Livestock (mainly yak) rearing and crop cultivation (including housewives farming part-time)	3	9	12	0	2	2	**3**	**11**	**14**
	Self-operated non-agricultural small or micro enterprise (especially tourism-related)	0	4	4	0	3	3	**0**	**7**	**7**
	Salaried job	0	0	0	0	1	1	**0**	**1**	**1**
	Non-farming housewife	1	0	1	2	0	2	**3**	**0**	**3**
	Retired and not working	0	1	1	2	1	3	**2**	**2**	**4**
	Student or unemployed	0	1	1	0	0	0	**0**	**1**	**1**

6	**Educational attainment**									
	Illiterate	2	3	5	2	1	3	**4**	**4**	**8**
	Primary school	1	5	6	0	1	1	**1**	**6**	**7**
	Secondary school	1	6	7	1	3	4	**2**	**9**	**11**
	Diploma/degree	0	1	1	1	2	2	**1**	**3**	**4**

*F: Female, M: Male, T: Total
^Nominal per capita income derived from estimated income for interviewee's household; monetary values expressed in Indian Rupees (INR) and US Dollars (USD), currency exchange rate: USD 1 = INR 70

3.3.1.2. Ethnographic encounters in the Upper Mandākinī valley

I conducted extensive ethnographic fieldwork at the sacred, seasonally inhabited high-altitude settlement of Kédārnāth and the downstream villages of Gaurīkund, Trijugīnārāyan, and Dewalī Bhanigrām in the catchment of the Upper Mandākinī River in the Western Himalaya. Over a 34-day period in April-May 2016, a 19-day period in June 2016, and a 10-day period in September 2016, I conducted 30 interviews with community members in the Hindostānī/Hindī language, each of which lasted between one and seven hours. I also actively observed and participated in everyday community life, including activities such as communal tea-drinking and hymn singing, religious sermons and philosophical discussions, muleteering and portering along the pilgrims' trail, women's firewood collection trips, and routine farm-based and household chores. Beyond mid-May 2016, I could continue only with the more sedentary of these engagements, owing to temporary lower-body disablement in the aftermath of a dog attack that many local residents attributed to bad karma from a previous life and the resultant wrath of the dog-riding deity Bhairava.

Throughout the fieldwork period, I maintained descriptive, place-centred ethnographic field notes in English and Hindī, both as audio-recorded logs (some of which were later transcribed and enriched) and as end-of-day diary entries. Apart from reflecting on my own positionality as a researcher, these notes often captured my personal impressions of the moods or atmospheres of certain places and social situations, as conjured up by the local cultural meanings, emotionalities, and spiritualities attached to them. My account of my arrival in Kédārnāth on foot, based on a transcribed and edited audio-recorded commentary, is presented below to give the reader a situated sense of the UM pilgrimage culture and landscape:

> I had a sleepless night in a noisy cluster of multi-storey concrete-walled pilgrims' lodges in Gaurīkund (lit. 'goddess's pool'), an otherwise quiet and traditional priestly village located at the end of a part-tarmac motorable road in a 2,000-metre-high stony gorge in the rugged Garhwāl Himālaya. Just before daybreak today, I poured an urn-ful of cold water over my tired body, and donned a starched white *kurtā-pyjāmā* (long cotton shirt and trousers). Standing in front of the mirror, I stared thoughtfully into my own eyes, and made auspicious marks across my forehead with sandalwood paste and holy ash, ceremoniously bringing alive an otherwise dormant layer of my personality. This part of me relates to the performance of my locally esteemed (and, to some extent, expected) cultural identity as a young scholarly *brahmachārī* (celibate, morally virtuous 'seeker of the ultimate reality') whose ancestors were Brahmins (Hindu "supreme-caste" bearers of sacred knowledge) from Kashmīr, a Himalayan region locally imagined (usually in a casteist-supremacist sense) to have historically been home to the spiritually and intellectually "finest" and racially "purest", i.e. the most phenotypically "Caucasoid", specimens of

the Sanskrit-speaking Indo-Aryan people. Accompanied by a young White male lensman from England (with whom I intend to produce an audiovisual ethnographic portrait of the place) and two young male semi-literate "mid-caste" immigrant porters from high-mountain northwestern Nepāl (who have been carrying our heaviest bags on their hunched backs), I started to follow the constantly growing swarm of devotees quite soon after dawn.

For the last several hours, we have been trudging up the imposing, heavily scarred valley of the River Mandākinī (lit. 'she who is moderate-paced'), a seemingly gentle headstream of the holy Ganges or Gangā Maiyā (lit. 'ever-flowing mother'), who is locally believed to have descended from the locks of the mountain-dwelling Lord Shiva (lit. 'the auspicious'), the embodiment of the Universe's destructive principle in Hinduism. It is now late afternoon. A cold rain has been beating down on us for two hours. We are still part of the 'swarm', which includes zealous pilgrim trekkers in identical disposable polythene raincoats – male and female, young and old, urban and rural, highly educated and illiterate, rich and poor - from eight different Indian states; saffron-clad *sādhu* (male ascetics) and *purohit* (male ritual-performing priests); cannabis-smoking *bābā* (holy men) with long dreadlocked hair and flowing beards; athletic male Népālī and Garhwālī (local) porters carrying food, furniture, construction material and even pilgrims in *kandī* (wicker baskets), *dāndī* (sedan chairs) and *dólī* or *pālkī* (palanquins); drenched, overloaded and constantly defecating belled mules; and humming horseflies. The steep and snaky but freshly paved trail has finally brought us to a flat treeless terrace just below what seems to the physical geographer in me a moraine ridge from the Last Glacial. In twenty minutes or so, we should be on the already visible 3,500-metre-high glacial outwash plain of Kédārnāth (Lord Shiva's local *rūpa* or manifestation, lit. 'lord of the quagmire'), where a majestic, millennium-old stone temple stands out amidst an unsightly hotchpotch of morainic boulders, metal and concrete rubble, silt-choked alleys, half-crumbling but revamped decades-old lodges, and a dense, refugee camp-like colony of canvas tents and sparkling tin-roofed prefabricated cabins.

I can hear distant drumbeats and an approaching crowd. It is the merry procession accompanying the *dólī* of Lord Shiva's heavily garlanded silver idol. The idol is being brought back to the Kédārnāth Temple after a six-month stay in Ukhīmath, which is more than 2,000 metres lower than Kédārnāth and therefore a far more temperate winter environment for the deity. Tomorrow, 9th May 2016, is the auspicious third lunar day of Vaishākha, the first summer month of the ancient Indian calendar. An astrologically opportune moment is expected to arrive tomorrow morning, when the idol may be placed in the temple's dark *garbha-griha* (sanctum sanctorum; lit. 'womb-house') and the temple doors may be opened for *darshan* (holy sight) and *pūjā* (worship), marking the beginning of the *tīrtha yātrā* (lit. 'transformative pilgrimage') season. But before that, the priests must seek permission and guidance from Bhairava, the dark, dreadful dog-riding guardian deity, whose rock-carved idol sits watchfully amidst black and blood-red flags atop a high Last Glacial moraine on the eastern side of the valley.

A sharp icy wind howls through the valley, swiftly scooping out all the dark clouds to reveal a colossal wall of glistening ice, snow and debris at the head of the valley. This is our first *darshan* of the south face of the nearly 7,000-metre-high Kédārnāth Mountain – a truly stunning sight. The rocky summit glows like gold in the afternoon light. Our porters remark that it looks much like the hump on the back of Nandī, the legendary bull that serves as Lord Shiva and his consort Goddess Pārvatī's (lit. 'she who comes from the mountains') vehicle. Two debris-covered glaciers – Chorābārī and Chorābārī East (aka 'Companion') – can be seen slithering down the mountain, separated by a massive ridge of morainic debris, which looms over the Kédārnāth Temple. The meltwaters emanating from these glaciers are respectively called Mandākinī and Sarasvatī (named after the Hindu goddess of knowledge, wisdom and creativity). They flow in sharply eroded channels on either side of Kédārnāth and then come together with a great force at an acute angle, making the settlement seem like an island.

One immediately tries to visualise what the valley would have looked like during the June 2013 pilgrimage disaster, when extremely intense rain triggered two enormous, metres-thick morainic debris flows, which devastated Kédārnāth and dozens of riverside settlements downstream, killing several thousand people. The first flood, which occurred on the evening of 16th June, had originated on the northeastern (Chorābārī East Glacier) side of Kédārnāth and travelled along the Saraswatī channel. The second and more damaging event, which occurred on the morning of 17th June, had originated on the northwestern (Chorābārī Glacier) side and travelled along the steep Mandākinī channel; it had involved the sudden emptying of a high lateral moraine-dammed meltwater lake (named Chorābārī Tāl or Gāndhī Sarovar, after Mahatma Gandhi, whose ashes were immersed in it in 1948) following a supposed mass movement into its rain-augmented waters and the subsequent failure of the previously stable impounding moraine. By the following day, the flooding had affected the entire Upper Ganges Basin and had grown into a full-blown disaster across the state of Uttarakhand. Coincidentally, 18th June in 2013 was Gangā Dashaharā, a Hindu festival that marks the mythological anniversary of the descent of the sin-extinguishing Ganges upon Earth.

Visibly humbled by the sheer enormity of the landscape, some pilgrims fold their hands while chanting *"Om Namah Shivāya!"* (lit. 'Salutations to Shiva!'), *"Jai Ho!"* (lit. 'Victory!' or 'Glory!'), or *"Hara Hara Mahādéva!"* (lit. 'Sweep away, sweep away [vice or the ego], O Great Lord!'); others make deep obeisances to the mountain itself, hailing it as an earthly image of Lord Shiva's heavenly abode.

The local population of the UM valley comprises remote, fundamentally agrarian (but seasonally pilgrimage tourism-centred and increasingly mercantile), ethnically homogeneous Hindu "high"-caste (almost entirely Brahmin or priestly/scholarly-caste) Garhwālī communities [several thousand persons altogether]; a sizeable but socially unassimilated "mid"- and "low"-caste immigrant worker community (male porters, muleteers, construction workers and other manual labourers) mainly from high-mountain northwestern Népāl but also from Indian lowland regions such as Bihār [several hundred persons]; and a large, socio-culturally and economically heterogeneous mass of seasonal Hindu pilgrims from across India [a few hundred thousand visitors from early May until late October, averaging a few thousand per day]. Kédārnāth and other pilgrim-hosting settlements along the Mandākinī River also seasonally attract hundreds of Garhwālī male workers from nearby villages that are not on or near the pilgrimage route.

From the above population, I interviewed 30 residents (see Table 3.5 for demographic details). They were purposively chosen so as to ensure that the sample reflected the ethnic (locals vs. migrant workers) and occupational (farming vs. pilgrimage tourism economy) diversities present in the summertime resident population. The UM pilgrimage tourism economy (comprising such activities as priestly work, small businesses such as shops and pilgrims' lodges, local taxi services, muleteering, portering, and other manual work) is almost entirely male-operated. Therefore, a special effort had to be made to engage with the experiences of females whose family members seasonally live and work in Kédārnāth or the associated pilgrimage route along the Mandākinī River. Such females were interviewed in agricultural hamlets that are off the main pilgrimage circuit, but supply male workers to the seasonal pilgrimage economy. All this was done while trying to ensure that dwelling clusters with high levels of exposure to geohazards were represented to some extent.

The selected sample of 30 included: (i) disaster-surviving local male priests and immigrant male manual workers in the female-scarce seasonal high-altitude settlement of Kédārnāth (10 males of ~612 non-pilgrim residents, >99% male); (ii) men and women in the downstream villages of Gaurīkund (3 males and 2 females of ~223 local residents, 60% male) and Trijugīnārāyan (4 males and 5 females of ~1,360 residents, 50% male); and (iii) only women in the more distant village of Dewalī Bhanigrām (6 women of ~1,188 residents, 50% male prior to the disaster-related deaths of about 10% of all males in 2013). In addition, 10 pilgrim-tourists from various parts of India were informally interviewed about risks associated with the pilgrimage as well as topics relating to faith, the environment, and development.

I enjoyed privileged, insider-like access to homes and minds in the UM community, owing to the "venerable" traits associated with my caste-and-ethnicity-based cultural persona, my choice of a highly Sanskritised (i.e. "refined" and "markedly Hindu priestly") register of the Hindostānī language, and my utterly desirable replies to community members' "screening" questions relating to my social and moral credentials. The most typical of such questions were as follows: "You are a *panditjī* (learned Brahmin), aren't you?"; "What is your *gotra* (prestige-linked 'cowshed clan' based on descent from an ancient sage)?"; "What do you do for a living?"; "What were your forefathers' professions?"; "If you are unmarried, I hope your *brahmacharya vrata* (vow of celibacy and piety) is still intact! You don't have any illicit lovers in England, do you?"; "I hope you haven't eaten beef in *vidésha* (foreign lands)?"; "You are Kashmīrī, and Kashmīr is full of Muslims – do they eat beef there?" During a 10-day period in May 2016, when a young White male filmmaker from England was travelling with me to collaboratively create an audiovisual ethnographic portrait[2] of the UM valley, similar enquiries were made about his moral credentials: "Although that camera lad with you is *vīdeshī* (foreign), he has a good complexion and seems *sīdhā* (righteous) and *bholā* (innocent) – I hope he will not commit any sacrilegious acts here?"; "Your friend's hair is dark, and he seems so *dūdh-kā-dhulā* (pure and innocent, lit. 'bathed in milk') – if indeed he is *vīdeshī,* he must come from a very good family?"; and "I hope the milky white man doesn't feel the need to consume alcohol or meat?". It was made amply clear that if I had not been a "well-spoken" "high-caste" Hindu with an adequately religious and pietistic attitude (or worse still, if I had been a young woman, or even a man, from an oppressed "low"/ex-"Untouchable" caste background, a visibly "Western"/"Westernised" cultural background, a Muslim/Judeo-Christian religious background, or a Black racial background), it would have been extremely difficult for me to make inroads into the conservative priestly culture of the UM valley.

---

[2] *As an outreach exercise independent of the dissertation, two ethnographic (interview- and observation-based) documentary films were made on the UM community in creative collaboration with two different British filmmakers. The first film, 'Facing the Mountain' (dir: Harrison and Kaul, 2016, 21 minutes), was shot during initial field engagements with the UM community, and the second film, 'Mountain, Priest, Son' (dir: Seddon and Kaul, 2018, 27 minutes), was shot 19 months after the end of fieldwork with the UM community. Both films are essentially audio-visual portraits of places in flux; owing to the centrality of place in their construction, they are arguably geographical documentaries. They explore how extraordinary geophysical, psycho-cultural, and socio-economic forces are coming together to shape the complex and rapidly changing everyday realities of communities in the UM valley. While the former film focuses on the 2013 disaster and the community's resilience in its immediate aftermath, the latter film begins to move on from the disaster per se, as it examines the community's culturally rooted understandings and ontologies of risk in the face of wider socio-environmental change.*

Table 3.5. Upper Mandākinī (UM) community: Demographic profile of interviewees

S. No.	Parameter		Number of interviewees		
			Female	Male	Total
1	**Sample size**	All settlements	13	17	30
		Kédārnāth	0	10	10
		Gaurīkund	2	3	5
		Trijugīnārāyan	5	4	9
		Dewalī Bhanigrām	6	0	6
2	**Age** (sample median: 39 years)	18-50 years	7	13	20
		Over 50 years	6	4	10
3	**Ethnicity**	Garhwālī "high"-caste	13	10	23
		Népālī "mid"-caste	0	5	5
		Lowland (Gangetic Plain) "low"-caste	0	2	2
4	**Annual income per capita***	Low *< INR 75,000 / < USD 1,071*	5	8	13
		Medium *INR 75,000-150,000 / USD 1,071-2,142*	6	6	12
		High *> INR 150,000 / > USD 2,142*	2	3	5
5	**Principal occupation**	Farming (including housewives who are part-time farmers with or without additional income-generating work such as weaving)	8	2	10
		Portering, muleteering, or other manual work such as construction	0	8	8
		Priestly services or other self-operated non-agricultural small or micro enterprise (especially pilgrimage-related)	2	5	7
		Salaried government job	1	2	2
		Retired and not working	2	1	3
6	**Educational attainment**	Illiterate	4	2	6
		Primary school	3	5	8
		Secondary school	4	4	8
		Diploma/degree	2	6	8

*Nominal per capita income derived from estimated income for interviewee's household; monetary values expressed in Indian Rupees (INR) and US Dollars (USD), currency exchange rate: USD 1 = INR 70

The rich descriptive material (transcripts of audio-recorded interviews, observation notes, and documentary photographs and videos) generated through the above interactions were compiled, indexed (through literal, interpretive and reflexive readings: Mason 2002b) and explored with the help of qualitative data analysis software (QSR NVivo). Open coding was employed to identify categories and sub-categories in the data, and then axial coding was performed to make connections between each category and its sub-categories and to discover relationships among categories (Corbin and Strauss 2015). The understanding of risk and adaptive capacity that emerged from this analysis of ethnographic data was fundamental to the development of the dissertation and its contribution to knowledge. It was supplemented by data obtained through focus group discussions and participatory mapping exercises with community members as well as some additional elite interviews with public administrators.

3.3.2. Focus group discussions, elite interviews, and participatory mapping

In each community, three focus group discussions (FGDs) were conducted with three different sets of six persons (see Appendix 2B for outline). The first focus group was constituted spontaneously at a communal place (e.g. village community centre, tea shop) and was used prior to the ethnographic interviews for gaining a preliminary understanding of the social and environmental setting and obtaining feedback on the research questions and interview schedule (Morgan 1997, Krueger and Casey 2008). The second FGD was held with well-informed community elites such as members of the elected village-level self-government body. This discussion focused on planning-related, managerial/logistical, financial, and technical aspects of community-level disaster risk reduction and climate change adaptation. It also included brainstorming exercises aimed at eliciting local ideas for a village-level adaptive strategy. Risk governance issues, particularly the planning and policy dimensions of disaster management and climate change adaptation, also drove brief, specialised semi-structured interviews with key public administrators (elites: see Dexter 2006) – four at the district and state levels in each study area, and three in the national (federal) government (see Appendix 2C for outline).[3] These interviews were conducted in conjunction with a review of the content of national- and state-level legislative and planning documents relevant to the management of climate-related geophysical risks in India (see Section 6.2.4).

Women had been insufficiently represented in the community interviews and other FGDs, so a third FGD was arranged in an all-female cross-class setting (a women's collective) in each community to examine livelihood issues and gender-based and other disparities in the context of vulnerability, resilience, and adaptive capacity. This final women-only FGD worked like a group interview in both communities. Due to the presence of a male moderator (myself), the female focus group members expressed some self-conscious shyness and tended to briefly whisper amongst themselves before formally presenting a single consensus response to each issue that was raised; they rarely responded to one another's verbal inputs in a cascading manner, and there was a certain degree of groupthink.

Overall, the FGDs strengthened ethnographic interview findings, especially those relating to the socio-economic and managerial dimensions of the communities' adaptive capacities (see Chapter 6), by facilitating methodological triangulation (Denzin 1989). Besides, the nature of social interactions among community members during the FGDs shed additional light on some important sociological aspects of adaptive capacity, such as group cohesion and cooperativeness (Morgan and Spanish 1984). Transcripts and memoranda from FGDs and key administrator interviews were analysed with the help of qualitative data analysis software (QSR NVivo) in a similar manner to community interview and observation data.

Participatory mapping excercises, undertaken as an extension to the first (exploratory) FGD, involved community members spatially recording their own culturally rooted, folkloristically embodied technical

[3] *Owing to stringent confidentiality requirements, the specific professional roles or departmental affiliations of these government officials cannot be disclosed. These respondents also cannot be quoted individually; their anonymised inputs must be aggregated before being integrated into any discussion in the dissertation.*

knowledge and metaphysics of local landscape dynamics and geohazards. This was achieved through group activities such as: (i) asking participants to illustrate their understandings of geomorphic processes and imaginations of associated risks using sticks, twigs, stones, gravel, sand and water on soft ground and coloured markers on paper; (ii) using a handheld GPS device to map physical and cultural landscape features as perceived by participants on walks through and around their village; and (iii) spatially recording participants' oral descriptions of landscapes viewed with them from vantage points (IFAD 2009, Kaul 2012, Kaul and Thornton 2014). The outputs of these exercises were systematically compared with available Western scientific geohazard assessments. The comparisons were performed, displayed, and interpreted spatially (see Sections 5.2 and 5.3, especially Figs. 5.1, 5.3, 5.40, 5.41, 5.42). An interesting observation made during these engagements with the communities' sense of spatiality was that it combined features that physically existed on the ground with mythical/legendary embodiments of metaphysical or moral-spiritual principles (e.g. *térma* or hidden treasures of virtue in ULC, *jyotirlinga* or radiant cosmic phallic pillar in UM) that were physically non-existent but believed to be esoterically locatable in the physical landscape.

3.3.3. Strategic planning

The empirical findings regarding Western scientific and local understandings of climate-related geophysical risks and both communities' adaptive capacities in the face of those risks were synthesised to propose a holistic strategic framework for culturally appropriate climate change adaptation and disaster risk reduction, especially in remote developing-word high-mountain settings (see Chapter 7). For this purpose, the strengths of the communities, the opportunities available to them, and their aspirations were mapped in relation to their largely self-appraised capacities to undertake adaptive practices that could help them persist functionally in the face of climate-related geophysical risks, or to incrementally modify or radically transform their functional character (see Table 7.1). The tool employed to execute this process was an adapted version of SWOT analysis – a common strategic planning procedure that involves recording in a matrix the internal strengths (S) and weaknesses (W) as well as the external opportunities (O) and threats (T) that are expected to support or impede the progress of a social agent (in this case, the two communities) towards a strategic goal (in this case, climate change adaptation and disaster risk reduction; for the only previous application in this context, see Kaul and Thornton 2014). SOA analysis, the variant of SWOT used in this study, excluded weaknesses (W) and threats (T) and incorporated aspirations (A) in response to relatively recent calls for an appreciative approach to strategising – one that replaces the negative, potentially demoralising/stigmatising emphasis on mitigating weaknesses and threats with a positive, potentially uplifting/inspiring focus on building upon strengths while reimagining any gaps as opportunities for improvement or aspirations towards a better future (Srivastava and Cooperrider 1999, Stravos and Sutherland 2003, Stravos et al. 2007, Stravos and Hinrichs 2007, Cooperrider et al. 2008, Stravos 2013). These positive motivational effects and strategic benefits of engaging with the positive aspects of a system (working with what already works) rather than its problems (working on what does not work) are also one of the key reasons why this study examines risk through the adaptive capacity lens rather than by assessing vulnerability (see Engle 2011, Handmer 2003; see also Section 2.2.2).

The adaptive capacity appraisal-derived community SOA analysis was based on *AdapT* (see Section 7.1) – a novel conceptual model of adaptive capacity proposed by this study – which uses practice theory to integrate the vulnerability and resilience perspectives on adaptation and risk reduction (see Section 2.2.2). The *AdapT* framework was iteratively developed during fieldwork – by initially applying vulnerability/resilience theory to the case study communities' everyday practical engagements with geophysical risk on the ground, and then using the resultant field-based empirical insights to review and refine conceptual thinking. In this manner, the in-depth place-based case study methodology acts as a conduit for conversations between the empirical and the theoretical, ultimately helping to deliver adaptive solutions that work on the ground (Ford et al. 2010).

3.4. Combining multiple methods and perspectives

A central feature of this dissertation is its integrative methodology, which draws together multiple academic disciplines and the diverse ontological stances, epistemic perspectives, and research methods that come with them. This means, for example, that inherently realist and positivist quantitative analyses offered by Climatology and Geomorphology are embraced concurrently with constructivist and interpretivist qualitative ethnographies offered by Cultural Anthropology (see Chapters 4 and 5). Compounding this methodological multiplicity are epistemological colllaborations between modern/Western scientific and traditional/local knowledge systems (see discussion of "two-eyed seeing" in Section 2.1.2), between the conceptual paradigms of vulnerability and resilience (see Section 2.2.2, Chapter 6), and between the practical frameworks of climate change adaptation and disaster risk reduction (see Section 2.2.3, Chapter 7). The tenability of this rich medley may be challenged on the grounds that it attempts to reconcile intrinsically irreconcilable ontologies and epistemologies. However, the reconciliation it offers is a pluralist one in that its ambition is not to negotiate a compromise between disparate perspectives, but rather to approach the research problem from multiple coexistent standpoints, each of which adds value to the overall understanding of the problem. Arguably, this epistemological pluralism presents a highly pragmatic approach to the complex challenge of comprehensively and multi-dimensionally understanding human-environment interactions in the context of climate change-related geophysical risks (see Curtis and Oven 2012, Lane et al. 2011, Mazzocchi 2006, Kaul and Thornton 2014, Ford et al. 2016).

The dissertation's philosophical commitment to disciplinary and epistemic plurality also reflects and celebrates my own distinctive positionality as a researcher/observer – both in terms of my academic position within the fundamentally interdisciplinary "discipline" of Geography and a cultural background with a metaphysical heritage that straddles the divide between modern materialist urban/Western societies and traditional eco-spiritualist/mysticist rural Himalayan societies. The place-based empirical work that follows in Chapters 4-7 is indeed an expression of my long-cultivated aspiration to build such holistic, grounded, and practically useful understandings of human-environment relationships as are able to transcend the epistemic discontinuities and barriers that prevent free flows of knowledge and insight between diverse academic disciplines and cultures.

4. Exploring experiences of climatic change

A key ambition of this dissertation is to exhaustively and critically engage with local communities' understandings of climate-related geophysical risks in the changing environments of the Upper Lāchen Chú (ULC) Basin in the Eastern Himalaya and the Upper Mandākinī (UM) Basin in the Western Himalaya. As a first step towards that objective, it is imperative that I substantively address the following questions about the climatic changes that face communities in each of the two study regions: (i) What changes have residents observed in their climates over the past few decades, and how do these appraisals compare with regional- and local-scale climatological observations and projections, particularly in the context of extreme precipitation?; (ii) How do the climatic changes that the residents report matter to their communities?; and (iii) Why do the residents think those changes have occurred?. Each of these questions constitutes a section of this chapter.

In an attempt at a holistic exploration of local experiences of climatic change among the ULC and UM communities, I integrate primary hydroclimatological analyses and reviews of published regional climatological observations and model projections with data from community interviews, including brief ethnographic commentaries. As I delve deeper into the communities' understandings of environmental change, a discussion on causality, as shaped by culturally embedded ontologies, moralities and emotionalities, begins to emerge, which is more fully developed in the context of risk in Chapters 5 and 6. Owing to its inseparability from conceptions and lived experiences of environmental change and associated risks, social change remains a salient background theme throughout the latter half of the chapter.

By placing physical scientific and socio-cultural data into the context of each other, I endeavour, both in the current chapter and in Chapter 5, to enable an epistemic dialogue and partnership between "local"/"external", "lay"/"expert", and "traditional"/"scientific" understandings of environmental dynamics, which arguably has the potential to allow each kind of knowledge to plug the gaps in the other (see Lane et al. 2011, Mazzocchi 2006, Berkes et al. 2000). This must eventually result in a richer functional knowledge of risk and positive outcomes for climate change adaptation and disaster reduction.

4.1. How has the climate changed?

In this section, I compare local-scale community narratives (see Tables 4.1 and 4.2) with published regional-scale analyses of instrumental records of temperature and precipitation change over the past few decades (see Appendices 4A.1, 4B.1) as well as my own primary statistical analysis of trends in indices of extreme summer monsoon precipitation (see Appendix 4C), which is known to be the key trigger for glacial lake outburst floods (GLOFs) and all kinds of landslides in Himalayan environments (Richardson and Reynolds 2000, Petley et al. 2010, Petley 2012). I also briefly explore changes in precipitation variability. In addition, I review model projections of regional temperature and precipitation change over the 21st century (see Appendix 4B) in the context of local observations of ongoing climatic change. Precipitation change, particularly that relating to extremes during the summer monsoon season, remains the focus of the discussion, owing to its direct implications for disaster risk.

The communities' subjective observations of climatic change over the past few decades are summarised below. The regional climatological analyses undertaken in the rest of Section 4.1 relate mainly to these observations.

Overall, both the ULC and the UM communities report having witnessed the following climatic changes over the past few decades: (i) climate warming, particularly in the winter; (ii) sharp declines in snowfall, particularly in early winter; (iii) reduced summer monsoon precipitation, albeit with greater extremes in terms of heightened rainfall intensity and more frequent short-spell high-intensity rainfall events; and (iv) greater intra-seasonal and inter-annual temperature and precipitation variability. (v) Notably, both communities observe the greatest increases in both temperature and rainfall intensity to have occurred at the highest elevations. (vi) Besides, the ULC community reports wetting in April, while the UM community reports intensification of June precipitation (see Table 4.1).

In terms of climate-linked changes in the physical landscape, both communities report: (i) retreat and thinning of glaciers; (ii) upward altitudinal shifts in snowlines; (iii) reduced snow pack volumes and longevity; (iv) reduced winter avalanche occurrence; and (v) increased monsoon landslide density and frequency. (vi) The UM community also observes that mountain springs, a major source of rural domestic water supplies, are drying up, and that small groundwater-fed and snowmelt-fed streams are more frequently dry in the pre-monsoon early summer season (see Table 4.2).

Table 4.1. Community observations of climatic change over the past few decades*

Community →	**Upper Lāchen Chú (ULC)** *N=30**			**Upper Mandākinī (UM)** *N=25**		
Direction of observed change →	**Rise**	**Fall**	*Can't say*	**Rise**	**Fall**	*Can't say*
Season / Parameter ↓	*Figures indicate % of interviewees reporting a particular change*					
Summer						
Temperature	**83%**	13%	*4%*	**72%**	24%	*4%*
Intra-seasonal temperature variability ("fluctuation within each season")	**93%**	0%	*7%*	**100%**	0%	*0%*
Inter-annual temperature variability ("fluctuation on a year-to-year basis")	**87%**	0%	*13%*	**76%**	0%	*24%*
Monsoon rainfall amount	0%	**80%**	*20%*	36%	**64%**	*0%*
Intra-seasonal rainfall variability	**90%**	0%	*10%*	**88%**	0%	*12%*
Inter-annual rainfall variability	0%	0%	*100%*	**92%**	0%	*8%*
Rainfall intensity	**90%**	0%	*10%*	**100%**	0%	*0%*
Frequency of short-spell, high-intensity rainfall	**90%**	0%	*10%*	**100%**	0%	*0%*
Rainfall timing: *Peak shift towards late summer*	**70%**			**68%**		
Winter						
Temperature	**100%**	0%	*0%*	**100%**	0%	*0%*
Intra-seasonal temperature variability	**80%**	0%	*20%*	**100%**	0%	*0%*
Inter-annual temperature variability	**70%**	0%	*30%*	**100%**	0%	*0%*
Snowfall amount	0%	**100%**	*0%*	0%	**100%**	*0%*
Inter-annual snowfall variability	**77%**	0%	*23%*	**100%**	0%	*0%*
Snowfall timing: *Peak shift from early winter towards spring, resulting in shallower and shorter-lived snow packs*	**93%**			**100%**		
Other observations	*(i) Increases in both temperature and rainfall intensity are the greatest at the highest elevations (73%).* *(ii) Unusually prolonged spells of unusually heavy rain have become more frequent in April (73%).* *(iii) The frequency of October hailstorms has increased (70%).* *(iv) The frequency of unseasonal (especially April-early May and October-early November) snowfall events has increased (70%).*			*(i) Increases in both temperature and rainfall intensity are the greatest at the highest elevations (80%).* *(ii) June thunderstorms have become more "explosive" or "noisier" (80%), and more frequent (56%).* *(iii) May-June rainfall has become more spatially variable at the catchment scale, and high-intensity rainfall events are often extremely localised (84%).*		

**This summary is based on both first-hand and second-hand historical accounts provided by those interviewees who have been living in the community for at least one decade (all interviewees in Upper Lāchen Chú and 83% in Upper Mandākinī).*

Table 4.2. Community observations of climate-linked changes in the physical landscape over the past few decades*

Community → Landscape component ↓ *(Relevant climatic changes)*	**Observed changes** *Figures in parentheses indicate % of interviewees reporting a particular change*	
	Upper Lāchen Chú *N=30**	**Upper Mandākinī** *N=25**
Glaciers *(Climate warming, snowfall decline)*	Retreat and thinning (93%)	Retreat (88%) Retreat and thinning (72%)
Snowline elevation *(Climate warming, snowfall decline and timing changes)*	General increase (93%)	Increase in end-of-monsoon or pre-winter (climatic) snowline elevations (100%) Increase in end-of-winter or early summer snowline elevations (92%)
Winter snow packs *(Climate warming, snowfall decline and timing changes)*	Decline in snow depths and snow cover area and duration (100%)	Decline in snow depths and snow cover area and duration (100%)
Winter avalanches *(Climate warming, snowfall decline)*	Decline in frequency and magnitude (73%)	Thinning and shrinkage of quasi-perennial snow avalanche deposits (firn packs) along gullies/couloirs and torrent channels (locally referred to as "glaciers" or "where the glacier comes") (80%)
Monsoon landslides *(Increased extreme rainfall)*	Increase in landslide density (76%)	Increase in landslide density and magnitude (100%).
Dry season water sources *(Climate drying, climate warming)*	- - -	Mountain springs are drying up (92%). Small groundwater-fed and snowmelt-fed streams are more frequently dry in the relatively warm and dry pre-monsoon period that extends from mid-April until mid-June (84%).

**This summary is based on both first-hand and second-hand historical accounts provided by those interviewees who have been living in the community for at least one decade (all interviewees in Upper Lāchen Chú and 83% in Upper Mandākinī).*

4.1.1. Temperature

4.1.1.1. Observations of temperature change

A review of published regional-scale analyses of temperature change over the past half century in the Eastern Himalaya, Northeast India, the Tibetan Plateau, and the Indian state of Sikkim (all corresponding to the ULC community) as well as in the Western Himalaya and the Indian state of Uttarakhand (both corresponding to the UM community) confirms, overall, the communities' reports of warming and of more conspicuous warming in winter (December-February) than in other seasons (see Appendix 4A.1 for details). The Himalayan region as a whole has warmed up at an average rate of about 0.2°C per decade since the mid-20th century, which is roughly equivalent to the average rate of global land surface temperature rise (Ren et al. 2017). Over the last four decades, climate warming in the Himalaya has accelerated sharply, with annual and wintertime mean temperatures rising at regionally averaged rates of about 0.6°C and 0.7°C per decade, respectively, during 1982-2006 (Shrestha et al. 2012).

Evidence of altitude-dependent warming from Tibet and the Eastern Himalaya is in agreement with the communities' observation that warming over the past few decades has been the greatest at the highest elevations (Yan and Liu 2014, Shrestha and Devkota 2010, Liu et al. 2009). It is at these highest elevations that glaciers exist, which are reported by local communities as well as regional glaciological studies of both Uttarakhand and Sikkim to have seen significant mass losses over the past few decades (Bhambri et al. 2011, Kumar et al. 2013, Bolch et al. 2012, Raina 2009).

A notable exception to the observed tendency towards a warmer climate is that the 1951-2010 instrumental record for Uttarakhand in the Western Himalaya (Rathore et al. 2013: India Meteorological Department) indicates statistically significant declines in minimum temperatures for the March-May pre-monsoon early summer season and the June-September summer monsoon season, which more than offset slight concurrent summertime maximum-temperature increases, leading to declining summertime mean temperatures. This is not entirely congruent with, but is reflected to some extent by, the much higher level of agreement in the UM community over wintertime warming (with 100% reporting warming) than over summertime warming (with 24% reporting cooling despite the severe, possibly El Niño-related, early-summer heat waves and forest fires of 2015 and 2016, memories of which were fresh in the summer of 2016, when the interviews were conducted). Yadav et al. (2014) use dendrochronological temperature reconstructions as well as instrumental records to confirm early summer cooling in the Western Himalayan region over the late 20th century, which they attribute to minimum temperature declines and concomitant diurnal temperature range increases caused by local-scale forcing from extensive deforestation and land degradation. Nonetheless, the numbers of cold days (maximum temperature ≤10th percentile) and cold nights (minimum temperature ≤10th percentile) in early summer do show statistically significant reductions in the Western Himalaya over 1970-2005 (Kothawale et al. 2010).

4.1.1.2. Projections of temperature change

Available national-scale climate change projections for India, regional-scale projections for the Hindu Kush-Himalaya (HKH) mountain system and its various segments (with the Western and Central Himalaya corresponding to the UM community and the Eastern and Central Himalaya corresponding to the ULC community), and sub-regional-scale projections for the Indian provinces of Uttarakhand (corresponding to UM) and Sikkim (corresponding to ULC) as well as relevant districts and individual gridded model output cells within each of these provinces were also reviewed (see Appendix 4A.2 for details). For both communities, these projections unanimously indicate considerable climate warming over the rest of the 21st century, which is expected to be more pronounced in winter than in summer. For example, Sanjay et al. (2017) project for the HKH2 Central Himalayan region (at whose western and eastern ends, respectively, the UM and ULC communities are located) warming of 4.3°C (CORDEX multi-RCM (regional climate model) ensemble mean) in the June-September summer monsoon season for 2066-2095 relative to 1976-2005 under Representative Concentration Pathway (RCP) 8.5. RCP 8.5 is the steepest of the four atmospheric greenhouse gas concentration trajectories defined in the IPCC's fifth assessment report (2014), which assumes that emissions will continue to rise beyond the end of the 21st century (IPCC 2013). The corresponding RCP 8.5 projection for wintertime (December-February) temperature rise in the Central Himalayan region is even more severe at 6.0°C (Sanjay et al. 2017). These projected temperature increases for the Central Himalaya are considerably greater than the mean extent of global surface warming expected by the late 21st century under RCP 8.5, which stands at about 3.7°C (see Appendix 1B).

Besides increases in mean temperatures, high-temperature extremes are expected to become more frequent. This is exemplified by the Nepal Climate Vulnerability Study Team's (2009) 15-model ensemble prediction of mean increases of 65% and 72%, respectively, for the gridded model output data cells corresponding to North Sikkim (ULC community) and Garhwal (UM community), in the number of hot days (when the maximum temperature exceeds the 95th percentile) in December-February by the 2090s relative to 1970-1999 under the A2 greenhouse gas emissions scenario of the IPCC's (2000) Special Report on Emissions Scenarios (SRES) (see Appendix 1A for details of scenarios). Likewise, low-temperature extremes are expected to become less frequent. This is exemplified by Rao et al.'s (2018) PRECIS-based projection of a reduction of 1.57 frost days (when the minimum temperature remains below 0°C) in December-February for the Rudraprayag district (UM community) by 2021-2050 relative to 1961-1990 under the SRES A1B scenario. These projections are in agreement with both communities' observations of ongoing warming and of particularly pronounced warming in the winter, which has direct implications for snowfall and glacial mass balances, as also for a range of glacial and periglacial hazards operating in already-thermally-perturbed high-altitude geomorphic systems (see Evans and Clague 1993, 1994; Richardson and Reynolds 2000; Huggel 2009).

4.1.2. Precipitation

4.1.2.1. Observations of precipitation change

The Hindu Kush-Himalayan region as a whole appears to have witnessed climate wetting with an increase in both mean and extreme precipitation over the past half century, as indicated by Zhan et al. (2017), who report for the observational period 1961-2012 statistically significant upward trends in total annual precipitation, annual precipitation received as amounts that equal or exceed the 90th percentile of wet-day precipitation, annual number of wet days, annual number of days with precipitation amounts equalling or exceeding the 90th percentile of wet-day precipitation, mean daily precipitation intensity for wet days with precipitation amounts equalling or exceeding the 90th percentile, maximum one-day precipitation, maximum three-day precipitation, and maximum five day precipitation (see Appendix 4B.1 for details). Although the climatological trend towards a wetter pan-regional climate (also reported over 1961-2013 by Ren et al. 2017) is not congruent with the two communities' majority reports of local-/sub-regional-scale precipitation decline over the past few decades, the observed tendency towards a more extreme precipitation regime is reflected in both communities' unanimous accounts of increases in high-intensity monsoon precipitation as well as observations of associated increases in landslide density.

In an analysis of the 1951-2010 instrumental precipitation records for the Indian states of Sikkim (corresponding to the Eastern Himalayan ULC community) and Uttarakhand (corresponding to the Western Himalayan UM community), Rathore et al. (2013, India Meteorological Department) show for both states statistically insignificant but declining trends in total annual precipitation as well as in precipitation during the individual seasons of summer monsoon (June-September) and winter (December-February). This is broadly in agreement with both communities' observations of climate drying, and may be relevant to the UM community's concern about mountain springs drying up (see also NITI Aayog 2017) and small groundwater-fed and snowmelt-fed streams being more frequently dry in the pre-monsoon early summer season (mainly May).

Rathore et al. (2013) observe over 1951-2010 a statistically significant upward trend is observed for April precipitation in Sikkim only. This supports the ULC community's observation of unusually prolonged spells of unusually heavy rain having become more frequent in April over the past few decades. Rathore et al. (2013) also report a rising but statistically insignificant trend in June precipitation in Uttarakhand over 1951-2010, which matches the UM community's observation of increasingly intense and frequent thunderstorms in June. Besides, both communities report a shift in the peak of monsoon precipitation towards late summer, which may be reflected in the statistically insignificant but downward trends for July precipitation in both Sikkim and Uttarakhand over 1951-2010, along with insignificant but rising trends for August precipitation in Sikkim and September precipitation in Uttarakhand over 1951-2010 (Rathore et al. 2013).

4.1.2.1.1. Monsoon precipitation over the past century *(see Appendix 4C for statistical summaries)*

In order to examine monsoonal precipitation change over the past century in greater depth, we use daily precipitation data for June-September from the India Meteorological Department stations at Darjeeling (1901-1996), Gangtok (1985-2014) and Mangan (2001-2015) in the Eastern Himalaya (corresponding to the ULC community) and from Dehradun (1901-2014) in the foothills of the Western Himalaya (corresponding to the UM community) to detect trends in 17 indices of precipitation and its extremes (see Appendix 4C for details), which are compared with corresponding community narratives of change.

(i) Trends from the Eastern Himalaya (reference stations relevant to ULC; see Table 4.3)

Darjeeling *(1901-1996; see Appendices 4C.1 - 4C.3 for statistical summaries)*

An analysis of daily June-September precipitation data using the non-parametric Mann-Kendall test reveals for the period 1901-1996 extremely significant ($p \leq 0.001$) declining trends in total seasonal monsoon precipitation, number of days with precipitation $\geq 99^{th}$ percentile, and total precipitation received as amounts $\geq 80^{th}$ percentile, $\geq 90^{th}$ percentile and $\geq 95^{th}$ percentile; very significant ($0.001 < p \leq 0.01$) downward trends in mean daily precipitation intensity, maximum one-day precipitation, maximum three-day precipitation, maximum five-day precipitation, number of days with precipitation $\geq 80^{th}$ percentile, $\geq 90^{th}$ percentile and $\geq 95^{th}$ percentile, and total precipitation received as amounts $\geq 99^{th}$ percentile; and moderately significant ($0.01 < p \leq 0.05$) downward trends in the number of wet days (days with at least 1 mm precipitation), mean wet spell length, and precipitation during the longest wet spell.

The above 1901-1996 trends towards drying with reduced precipitation extremes during the monsoon are more marked in August than in other monsoon months, and the same trends for June-September are on the whole less pronounced and less statistically significant over 1951-1996 than over 1901-1950. The decline in total seasonal June-September precipitation is moderately significant ($0.01 < p \leq 0.05$) over 1901-1950, but only marginally significant ($0.05 < p \leq 0.1$) over 1951-1996. Also, there are very significant ($0.001 < p \leq 0.01$) falling trends in mean daily precipitation intensity and total precipitation received as amounts $\geq 80^{th}$ percentile over 1901-1950, but these are statistically insignificant ($p > 0.1$) over 1951-1996; likewise, there are moderately significant ($0.01 < p \leq 0.05$) negative trends in the number of days with precipitation $\geq 80^{th}$ percentile and $\geq 95^{th}$ percentile as well as in the total precipitation received as amounts $\geq 90^{th}$ percentile and $\geq 95^{th}$ percentile over 1901-1950, for which the corresponding declines over 1951-1996 are insignificant ($p > 0.1$).

Besides the above differences, the period 1951-1996 shows a very significant ($0.001 < p \leq 0.01$) downward trend in mean wet spell length and a moderately significant ($0.01 < p \leq 0.05$) downward trend in the number of wet days during June-September, which are both in contrast to statistically insignificant ($p > 0.1$) upward trends for the same indices over 1901-1950. For July (the wettest month) in particular, matching 1951-1996 declines in the number of wet days and mean wet spell length are very significant ($0.001 < p \leq 0.01$), again marking a departure from statistically insignificant rising trends in the same indices over 1901-1950. Combined with the previously mentioned deceleration of precipitation decline, these trends towards greater reductions in wet days and mean wet spell length provide additional evidence of a moderate abatement of monsoon precipitation intensity decline during the period 1951-1996 relative to 1901-1950.

There are, however, two exceptions to the lessened decline in monsoon precipitation extremes observed over 1951-1996 relative to 1901-1950. Firstly, the total June-September precipitation received as amounts $\geq 99^{th}$ percentile shows a moderately significant ($0.01 < p \leq 0.05$) decline over 1951-1996, compared with only a marginally significant ($0.05 < p \leq 0.1$) decline over 1901-1950. The prominence of this exception is offset, however, by the previously observed fact that the negative trends in total June-September precipitation received as amounts $\geq 80^{th}$ percentile, $\geq 90^{th}$ percentile and $\geq 95^{th}$ percentile are all statistically significant ($p \leq 0.05$) over 1901-1950 but insignificant ($p > 0.1$) over 1951-1996. The second exception is that the maximum one-day precipitation for June-September shows a marginally significant ($0.05<p\leq0.1$) decline over 1951-1996, but only an insignificant ($p>0.1$) negative trend over 1901-1950. Even so, a contrasting tendency is seen in August (the second wettest month after July), where the trend in maximum one-day precipitation switches from a marginally significant ($0.05<p\leq0.1$) reduction over 1901-1950 to an insignificant ($p>0.1$) positive change over 1951-1996. August also shows changes from moderately significant ($0.01<p\leq0.05$) declining trends in maximum three-day and maximum five-day precipitation over 1901-1950 to insignificant ($p>0.1$) negative trends over 1951-1996. Besides, the trend in maximum five-day precipitation for the entire June-September season switches from an insignificant ($p>0.1$) negative one over 1901-1950 to an insignificant ($p>0.1$) positive one over 1950-1996.

Gangtok *(1985-2014; see Appendices 4C.4, 4C.5 for statistical summaries)*

An analysis of daily June-September precipitation data using the Mann-Kendall test reveals for the period 1985-2014 only statistically insignificant ($p>0.1$) rising trends in total seasonal precipitation, mean daily precipitation intensity, days with precipitation ≥80^{th} percentile, and total seasonal precipitation received as amounts ≥80^{th} percentile; however, upon splitting the 1985-2014 period into two halves – 1985-1999 and 2000-2014, marginally significant ($0.05<p\leq0.1$) upward trends are observed in total seasonal precipitation, mean daily precipitation intensity, and days with precipitation ≥80^{th} percentile for June-September over 1985-1999. The same trends are positive but insignificant ($p>0.1$) over 2000-2014.

For July alone, the entire 1985-2014 period shows a moderately significant ($0.01<p\leq0.05$) upward trend in the number of days with precipitation ≥80^{th} percentile and a marginally significant ($0.05<p\leq0.1$) upward trend in the total precipitation received as amounts ≥80^{th} percentile. Similar statistically significant ($p\leq0.1$) rising trends are, however, not observed for June-September, or even for July alone, in the number of days with precipitation ≥90^{th}, ≥95^{th} and ≥99^{th} percentiles or the total precipitation received as amounts ≥90^{th}, ≥95^{th} and ≥99^{th} percentiles. Statistically significant increases are also not observed in maximum one-day, three-day and five-day precipitation over 1985-2014, 1985-1999 or 2000-2014, except a marginally significant ($0.05<p\leq0.1$) positive trend in maximum five-day precipitation in July over 2000-2014. A probable explanation for the above situation, which cannot be verified without hourly precipitation data, is that, as reported by the community, extreme sub-diurnal precipitation events (e.g. those that last for several minutes or a few hours) have proliferated, which is likely reflected only in statistically significant increases in the number of days with precipitation amounts greater than the 80^{th} percentile but smaller than the 90^{th} percentile as well as in the total monthly or seasonal precipitation received as amounts that fall between the 80^{th} and 90^{th} percentiles for daily precipitation. This may be because despite their extreme, even potentially disastrous, intensities per minute or per hour, such precipitation events are still not large enough to exceed the 90^{th} or 95^{th} percentile for daily precipitation in a particular monsoon month or the entire monsoon season, or to have significant implications for the maximum one-day, three-day or five-day precipitation in that month or season. Such a scenario is illustrated by Thekchen, a ULC lodge owner and herdsman in his fifties:

"Until about twenty years ago, monsoon clouds would never be as tall and angry as they tend to be now. Also, raindrops have become much bigger… The water falls in much shorter spells now - sometimes we get a day's rain in a few minutes! That kind of rain is useless - it can only cause damage. When I was a child, we used to have good seven-day spells of kind rain… At times, it would even rain frogs on the sixth or seventh day!"

Another interesting observation is that mean and maximum wet spell lengths for June-September witness statistically insignificant (p>0.1) declines over 1985-2014 and 2000-2014, but show for the period 1985-1999 a moderately significant rise and a marginally significant rise, respectively. When seen in conjunction with the marginally significant (0.05<p≤0.1) increases in total seasonal precipitation, mean daily precipitation intensity, and number of days with precipitation ≥80th percentile during June-September over 1985-1999, these trends may again indicate a possible proliferation of short-spell, even sub-diurnal, high-intensity precipitation events in that period.

Mangan *(2001-2015; see Appendix 4C.6 for statistical summary)*

An analysis of daily June-September precipitation data using the Mann-Kendall test reveals for the period 2001-2015 only statistically insignificant (p>0.1) rising trends in total seasonal precipitation, mean daily precipitation intensity, maximum one-day precipitation, number of days with precipitation ≥80th, ≥90th, ≥95th and ≥99th percentiles, and total seasonal precipitation received as amounts ≥80th, ≥90th, ≥95th and ≥99th percentiles; however, the month of August witnesses over the same period a marginally significant (0.05<p≤0.1) rise in maximum one-day precipitation as well as a moderately significant (0.01<p≤0.05) increase in the number of days with precipitation ≥99th percentile. Also moderately significant (0.01<p≤0.05) is a declining trend in mean wet spell length for July over 2001-2015, which is comparable to the statistically insignificant (p>0.1) but declining trends in mean and maximum wet spell length for June-September over the same period. Overall, a probable tendency towards shorter-spell, higher-intensity precipitation is indicated by the data.

Table 4.3. Eastern Himalaya: Selected key significant trends in monsoon precipitation indices over various multi-decadal periods (see Appendices 4C.1-4C.6 for details)

S. No.	Precipitation index	Season/ month	Observation period	Station	Mann-Kendall trend	Significance
1	Total seasonal precipitation	JJAS	1901-1996	DJG	↓	
2	Total seasonal precipitation	JJAS	1985-1999	GTK	↑	
3	Mean daily precipitation intensity	JJAS	1901-1996	DJG	↓	
4	Mean daily precipitation intensity	JJAS	1985-1999	GTK	↑	
5	Maximum one-day precipitation	JJAS	1901-1996	DJG	↓	
6	Maximum one-day precipitation	August	2001-2015	MGN	↑	
7	Maximum three-day precipitation	JJAS	1901-1996	DJG	↓	
8	Maximum five-day precipitation	JJAS	1901-1996	DJG	↓	
9	Days with precipitation ≥80th percentile	JJAS	1901-1996	DJG	↓	
10	Days with precipitation ≥80th percentile	JJAS	1985-1999	GTK	↑	
11	Days with precipitation ≥80th percentile	July	1985-2014	GTK	↑	
12	Days with precipitation ≥90th percentile	JJAS	1901-1996	DJG	↓	
13	Days with precipitation ≥95th percentile	JJAS	1901-1996	DJG	↓	

14	Days with precipitation ≥99th percentile	JJAS	1901-1996	DJG	↓	
15	Days with precipitation ≥99th percentile	August	2001-2015	MGN	↑	
16	Total precipitation received as amounts ≥80th p	JJAS	1901-1996	DJG	↓	
17	Total precipitation received as amounts ≥80th p	July	1985-2014	GTK	↑	
18	Total precipitation received as amounts ≥90th p	JJAS	1901-1996	DJG	↓	
19	Total precipitation received as amounts ≥95th p	JJAS	1901-1996	DJG	↓	
20	Total precipitation received as amounts ≥99th p	JJAS	1901-1996	DJG	↓	

Symbols: JJAS: June-September; DJG: Darjeeling, GTK: Gangtok, MGN: Mangan; ↑ ***Increasing*** *trend;* ↓ ***Decreasing*** *trend*
Colours denote asymptotic significance levels: **Purple: $p \leq 0.001$, Wine red: $p \leq 0.01$, Orange: $p \leq 0.05$, Yellow: $p \leq 0.1$.**

Overall impressions

On the whole, the hydroclimatological analysis for the three Eastern Himalayan stations suggests climate drying over the past century and the past half-century, with some intensification of monsoon precipitation and a likely increase in short-spell, high-intensity monsoon precipitation over the past three decades. This finds an echo in the words of Grandpa Tāshī, a felt-hatted octogenarian in ULC who still enjoys riding and whipping his horses and yaks:

> *"I think we had more summer rain in the days of my youth, but that rain was different; it was usually gentle enough not to wash our precious soil away. Nowadays, the water tends to come all at once - it's like somebody cracking a whip!"*

Karma, a middle-aged herdswoman, concurs:

> *"Summer rainfall has declined, but only slightly... In fact, monsoon storms have become far more powerful, especially on high pastures where there are no trees. When a lot of rain comes all of a sudden, our animals get all worked up and start running helter-skelter. Till about a decade ago, our yaks could easily stay in the open on rainy days, but the kind of rain we get now actually hurts the animals. That's why we've started keeping them in rainproof tents."*

Pembā sums it up in one line:

> *"Sudden downpours have replaced steady showers, especially in the upper reaches of the valley."*

In the high Eastern Himalayan valleys of Lāchen and Lhonák in North Sikkim (a 3,200-5,500-metre-high region that broadly corresponds to the ULC study area), the mean temperatures of the warmest and coldest months are estimated to have risen by 0.76 ± 0.25 and 3.65 ± 2 °C, respectively, between 1849-1850 and 2007-2010 (Telwala et al. 2013). There is ample climatological evidence of a positive relationship between altitude and the rate of climate warming across Tibet and the Eastern Himalaya over the last few decades (Yan and Liu 2014, Liu et al. 2009, Shrestha and Devkota 2010), which is congruent with the ULC community's own observation of the greatest warming at the highest elevations.

Theoretically, a ~7% increase in atmospheric moisture-holding capacity can be expected with every 1°C of temperature rise (Clausius-Clapeyron relation), and precipitation extremes have been shown by climate models to generally increase at similar rates in response to warming (Kharin et al. 2007, see also Meehl et al. 2007, Pall et al. 2007, Allen and Ingram 2002) and at even sharper rates in some empirical studies of hourly and sub-hourly precipitation extremes in parts of Europe (Lenderink and van Meijgaard 2010, 2008; Molnar et al. 2015). The above facts imply that there must be a positive relationship also between altitude and precipitation intensity increase, as has been reported climatologically by Ren et al. (2017) and anecdotally in the above interview quotes.

Due to the absence of obstructive vegetation and the presence of extensive glacial and periglacial hazards in high-elevation environments (e.g. loosely moraine-dammed lakes, morainic deposits destabilised by ice-core thawing, scree slopes, ice and rock avalanches, etc.), the ostensible elevation dependency in the rate of increase in precipitation extremes would translate into disproportionately large amplifications of geophysical risk in response to climate warming. This is a matter of concern for both the ULC and the UM communities.

(ii) *Trends from the Western Himalaya (reference station relevant to UM; see Tables 4.4 and 4.5)*

Dehradun *(1901-2014; see Appendices 4C.7 - 4C.9 for statistical summaries)*

The two highest one-day precipitation values recorded at Dehradun in June over the entire 1901-2014 observational period occur on 17 and 16 June 2013, the main days of the region-wide disaster that caused several thousand fatalities. At 370.2 mm, the value for 17 June 2013 is an astounding 4,808% of the 80th percentile, 944% of the 95th percentile, and 424% of the 99th percentile for daily precipitation in June; and at 219.9 mm, the value for 16 June 2013 is 2,856% of the 80th percentile, 561% of the 95th percentile, and 252% of the 99th percentile for daily precipitation in June. Likewise, the total precipitation recorded at Dehradun from 15 until 17 June 2013 is the highest value for consecutive three-day precipitation in June over 1901-2014; at 643.6 mm, it is 306% of the mean monthly precipitation value for June over the same centurial period. From a disaster risk standpoint, it would be useful to find out whether this particular extreme event was part of a longer-term tendency towards a more extreme precipitation regime for the month of June and the wider June-September monsoon season.

The mean monthly precipitation and mean daily precipitation intensity for June both show considerable increases (+42%) in Dehradun – from 175.36 mm (5.86 mm day^{-1}) during 1901-1959 to 250.36 mm (8.35 mm day^{-1}) during 1960-2014. An analysis of daily precipitation data using the non-parametric Mann-Kendall test reveals a moderately significant ($0.01<p\leq0.05$) rising trend in maximum three-day precipitation for June over the period 1901-2014. In addition, total monthly precipitation, number of wet days, maximum one-day precipitation, maximum five-day precipitation, precipitation during the longest wet spell, number of days with precipitation ≥80th percentile, number of days with precipitation ≥95th percentile, total precipitation received as amounts ≥80th percentile, and total precipitation received as

amounts ≥95th percentile all show somewhat significant ($0.05<p\leq0.1$) positive trends over the same period, indicating an overall increase in extreme precipitation along with wetting in June over the past century.

None of the above precipitation indices for June shows a statistically significant trend ($p\leq0.1$) over the period 1901-1950, whereas several indices show quite significant upward trends after 1950 - particularly over 1951-2000, but also over 1951-1980 and 1951-2014. These trends include very significant ($0.001<p\leq0.01$) increases in monthly precipitation, mean daily precipitation intensity, maximum three-day precipitation, and total precipitation received as amounts ≥80th percentile, ≥90th percentile and ≥95th percentile in June over 1951-2000; moderately significant ($0.01<p\leq0.05$) increases in maximum one-day precipitation, precipitation during the longest wet spell, and number of days with precipitation ≥90th percentile and ≥95th percentile in June over 1951-2000; moderately significant ($0.01<p\leq0.05$) increases in maximum three-day precipitation and precipitation during the longest wet spell in June over 1951-2014; and moderately significant ($0.01<p\leq0.05$) increases in monthly precipitation, number of wet days, mean daily precipitation intensity, number of days with precipitation ≥80th percentile and ≥90th percentile, and total precipitation received as amounts ≥80th percentile and ≥90th percentile in June over 1951-1980.

The intensification of June precipitation observed above is substantiated by Cho et al. (2016), who find that increased anthropogenic loading of greenhouse gases and aerosols has possibly caused changes to mid-latitude upper-tropospheric circulation patterns over northern India since the 1980s, leading to increasingly large rainstorms in June. They also show that 60-90% of the precipitation amounts specifically involved in the June 2013 extreme event can be attributed to post-1980 climate change.

Table 4.4. Dehradun, Western Himalaya: Selected key significant trends in June precipitation indices over various multi-decadal periods (see Appendices 4C.7, 4C.8 for details)

S. No.	Precipitation index (for *June*)	Observation period	Mann-Kendall trend	Significance
1	Total monthly precipitation	1901-2014	↑	
2	Total monthly precipitation	1951-2000	↑	
3	Total monthly precipitation	1951-2014	↑	
4	Total monthly precipitation	1951-1980	↑	
5	Mean daily precipitation intensity	1951-2000	↑	
6	Mean daily precipitation intensity	1951-2014	↑	
7	Mean daily precipitation intensity	1951-1980	↑	
8	Maximum one-day precipitation	1901-2014	↑	
9	Maximum one-day precipitation	1951-2000	↑	
10	Maximum three-day precipitation	1901-2014	↑	
11	Maximum three-day precipitation	1951-2000	↑	
12	Maximum three-day precipitation	1951-2014	↑	
13	Maximum five-day precipitation	1901-2014	↑	
14	Precipitation during longest wet spell	1901-2014	↑	
15	Precipitation during longest wet spell	1951-2014	↑	
16	Days with precipitation ≥80th percentile	1901-2014	↑	
17	Days with precipitation ≥80th percentile	1951-2000	↑	
18	Days with precipitation ≥80th percentile	1951-1980	↑	
19	Days with precipitation ≥90th percentile	1951-2000	↑	
20	Days with precipitation ≥90th percentile	1951-1980	↑	
21	Days with precipitation ≥95th percentile	1901-2014	↑	

22	Days with precipitation ≥95th percentile	1951-2000	↑	
23	Days with precipitation ≥95th percentile	1951-1980	↑	
24	Days with precipitation ≥99th percentile	1951-2000	↑	
25	Total precipitation received as amounts ≥80th percentile	1901-2014	↑	
26	Total precipitation received as amounts ≥80th percentile	1951-2000	↑	
27	Total precipitation received as amounts ≥80th percentile	1951-1980	↑	
28	Total precipitation received as amounts ≥90th percentile	1951-2000	↑	
29	Total precipitation received as amounts ≥90th percentile	1951-2014	↑	
30	Total precipitation received as amounts ≥90th percentile	1951-1980	↑	
31	Total precipitation received as amounts ≥95th percentile	1901-2014	↑	
32	Total precipitation received as amounts ≥95th percentile	1951-2000	↑	
33	Total precipitation received as amounts ≥95th percentile	1951-1980	↑	
34	Total precipitation received as amounts ≥99th percentile	1951-2000	↑	

Symbols: ↑ ***Increasing*** *trend;* ↓ ***Decreasing*** *trend*
Colours denote asymptotic significance levels: **Wine red: p ≤ 0.01, Orange: p ≤ 0.05, Yellow: p ≤ 0.1.**

For the entire June-September summer monsoon season, the Mann-Kendall test shows over the period 1901-2014 a moderately significant (0.01<p≤0.05) increasing trend in the number of wet days and marginally significant (0.05<p≤0.1) increasing trends in maximum wet spell length and precipitation during the longest wet spell but no statistically significant trend for any precipitation intensity indicator. Multi-decadal periods within the 1901-2014 dataset show notable contrasts in trends. The period 1901-1950 shows moderately significant (0.01<p≤0.05) increasing trends in the number of wet days, maximum wet spell length, mean wet spell length, precipitation during the longest wet spell, and number of days with precipitation ≥80th percentile as well as marginally significant (0.05<p≤0.1) increasing trends in total seasonal precipitation, maximum five-day precipitation, number of days with precipitation ≥90th percentile, and total precipitation received as amounts ≥80th percentile; however, 1951-1980 reports no significant trends at all, and 1951-2000 and 1951-2013 also report no significant trends except marginally significant (0.05<p≤0.1) declines in mean daily precipitation intensity, associated with statistically insignificant (p>0.1) negative trends in total seasonal precipitation and positive trends in the number of wet days.

In contrast to 1951-1980, the periods 1981-2013 and 2001-2013 show an intensification of June-September precipitation. This is evidenced by moderately significant (0.01<p≤0.05) increasing trends in total seasonal precipitation, mean wet spell length, and number of days with precipitation ≥80th percentile and ≥90th percentile over 1981-2013; marginally significant (0.05<p≤0.1) increasing trends in the number of wet days and total precipitation received as amounts ≥80th percentile and ≥90th percentile over 1981-2013; highly significant (0.001<p≤0.01) upward trends in maximum three-day precipitation as well as maximum five-day precipitation over 2001-2013; and marginally significant (0.05<p≤0.1) rising trends in total seasonal precipitation, mean daily precipitation intensity, precipitation during the longest wet spell, and total precipitation received as amounts ≥80th percentile and ≥90th percentile over 2001-2013.

Table 4.5. Dehradun, Western Himalaya: Selected key significant trends in monsoon (June-September) precipitation indices over various multi-decadal periods (see Appendices 4C.7, 4C.9 for details)

S. No.	Precipitation index (for *June-September*)	Observation period	Mann-Kendall trend	Significance
1	Total seasonal precipitation	1901-1950	↑	
2	Total seasonal precipitation	1981-2013	↑	
3	Total seasonal precipitation	2001-2013	↑	
4	Wet days	1901-2014	↑	
5	Mean daily precipitation intensity	1951-2000	↑	
6	Mean daily precipitation intensity	1951-2013	↑	
7	Mean daily precipitation intensity	2001-2013	↑	
8	Maximum three-day precipitation	2001-2013	↑	
9	Maximum five-day precipitation	1901-1950	↑	
10	Maximum five-day precipitation	2001-2013	↑	
11	Maximum wet spell length	1901-2014	↑	
12	Maximum wet spell length	1901-1950	↑	
13	Precipitation during longest wet spell	1901-2014	↑	
14	Precipitation during longest wet spell	1901-1950	↑	
15	Precipitation during longest wet spell	2001-2013	↑	
16	Days with precipitation $\geq 80^{th}$ percentile	1901-1950	↑	
17	Days with precipitation $\geq 80^{th}$ percentile	1981-2013	↑	
18	Days with precipitation $\geq 90^{th}$ percentile	1901-1950	↑	
19	Days with precipitation $\geq 90^{th}$ percentile	1981-2013	↑	
20	Total precipitation received as amounts $\geq 80^{th}$ p	1901-1950	↑	
21	Total precipitation received as amounts $\geq 80^{th}$ p	1981-2013	↑	
22	Total precipitation received as amounts $\geq 80^{th}$ p	2001-2013	↑	
23	Total precipitation received as amounts $\geq 90^{th}$ p	1981-2013	↑	
24	Total precipitation received as amounts $\geq 90^{th}$ p	2001-2013	↑	

Symbols: ↑ ***Increasing*** *trend;* ↓ ***Decreasing*** *trend*
Colours denote asymptotic significance levels: **Wine red: $p \leq 0.01$, Orange: $p \leq 0.05$, Yellow: $p \leq 0.1$.**

Overall impressions

On the whole, the hydroclimatological analysis for Dehradun suggests some wetting with an increase in extreme precipitation during the June-September monsoon season over the past three decades, but no intensification of precipitation at all over the past century or the past half-century. However, the month of June shows a considerable shift towards a wetter and significantly more extreme precipitation regime over the past century and particularly over the past half-century.

The above situation is reflected in the fact that only 36% of UM community interviewees report wetting while 64% report drying during the monsoon season over the "past few decades", all of them report increases in rainfall intensity and the frequency of short-spell high-intensity rainfall, and the majority report that thunderstorms have become more "explosive" or "noisier" as well as more frequent in June.

Rājéshwar, a retired UM community priest (who has just reprimanded his grandson for playing Eminem on the family's mobile phone), remarks:

> *"There isn't more rain, but there's more power in the rain – it's "killer" rain… bigger, louder, sharper and more violent than normal rain… Just like this scruffy boy's music… Our times were different… It used to rain for days, but gently. Everything was gentler then… That's why there were no disasters… except avalanches in the winter… but avalanches used to do their job softly, unlike "cloud-bursts" and "lake-bursts"!"*

Granny Sāvitrī, an octogenarian who lost her son in the June 2013 disaster, makes the same point even more animatedly:

> *"Cloudbursts… we hear of them all the time these days. What's wrong? Why have the clouds become so noisy and mischievous? A day's rain in five minutes, a week's rain in half an hour… and then the hot sun for many days… What's wrong? Only the Wise Lord knows!"*

Granny Champā, a boisterous turbaned countrywoman in her nineties, sounds equally agitated about summer rain:

> *"Rain is no longer as hearty as it used to be… When I got married and came here [1940s], there used to be good three- or five-day spells of* rim-jhim *[steady, gentle rain] in* sāvan *and* bhādon *[the rainy late summer months, usually mid-July – mid-September]. Now it's like freaking burps and vomit, constipation, burps and vomit, constipation! The rainy season has become strange. Sometimes there is too much rain, so much that our men, mules and millets become mud… sometimes there is so little that our springs and streams dry up… God plays these games, you know…. to put Man in his place."*

The above remark also points to increased intra-seasonal and inter-annual variability in summer monsoon precipitation, an observation that the vast majority of UM interviewees make. Although the focus of the chapter remains on precipitation intensity, the next sub-section uses climatological data from both Eastern and Western Himalayan stations to briefly examine precipitation variability changes over the past century.

(iii) Changes in monsoon precipitation variability

Eastern Himalaya: Gangtok (1985-2014) and Darjeeling (1901-1996)

The coefficient of variation for daily precipitation in June-September drops negligibly from 1.07 during 1985-1999 to 1.06 during 2000-2014 in Gangtok, and rises slightly over the longer term from 1.41 during 1901-1949 to 1.49 during 1950-1996 in Darjeeling. Likewise, the coefficient of variation for total seasonal precipitation in June-September drops slightly from 0.14 during 1985-1999 to 0.11 during 2000-2014 in Gangtok, and rises negligibly over the long term from 0.16 during 1901-1949 to 0.17 during 1950-1996 in Darjeeling. This indicates a lack of considerable precipitation variability changes in the June-September monsoon season. There are, however, two notable changes in precipitation variability during June, possibly reflecting changes in the extent to which the timing of the arrival of the southwest monsoon fluctuates. Firstly, the coefficient of variation for total monthly precipitation in June in Gangtok almost halves from 0.41 during 1985-1999 to 0.22 during 2000-2014, perhaps indicating a recent tendency towards greater regularity in the timing of monsoon arrival. Secondly, the coefficient of variation for daily precipitation in June in Darjeeling increases from 1.53 during 1901-1949 to 1.77 during 1950-1996, pointing to increased intra-monthly fluctuations in early monsoon precipitation between those periods.

Western Himalaya: Dehradun (1901-2014)

The coefficient of variation for daily precipitation in June-September increases slightly from 1.78 during 1980-1999 to 1.81 during 2000-2014 and decreases slightly over the long term from 1.82 during 1901-1959 to 1.78 during 1960-2014 in Dehradun. Likewise, the coefficient of variation for total seasonal precipitation in June-September rises slightly from 0.18 during 1980-1999 to 0.23 during 2000-2014 and drops slightly over the longer term from 0.24 during 1901-1959 to 0.21 during 1960-2014. However, precipitation variability shows a sharp rise over recent decades in the month of June, wherein the coefficient of variation for monthly precipitation more than doubles from 0.49 in 1980-1999 to 1.01 in 2000-2014, and that for daily precipitation grows from 2.26 to 3.10 between the same periods. This is reflected to some extent in the following statement made by Jagdīsh, a middle-aged lodge manager in UM:

> *"Some summers are so wet that thousands die… and then there are years when winter and spring are very dry, so there is hardly any water left by summertime… and then the monsoon rains just refuse to come. The weather was far more sensible and predictable till about fifteen or twenty years ago."*

More research needs to be done to ascertain whether the heightened precipitation variability in June is associated with greater inter-annual fluctuations in the timing of the arrival of the southwest monsoon or/and greater inter-annual and intra-monthly fluctuations in the interactions of extratropical upper-air westerly disturbances with tropical pre-monsoon and monsoon depressions in June (for cues, see Hong et al. 2011). Over the longer term, increases in precipitation variability for June at Dehradun are smaller, with the coefficient of variation for daily precipitation moving only slightly from 2.55 during 1901-1959 to 2.59 during 1960-2014 and that for monthly precipitation growing from 0.70 during 1901-1959 to 0.84 during 1960-2014.

4.1.2.1.2. Winter precipitation over the past century *(see Appendix 4D for statistical summaries)*

It would be useful to also examine changes in winter precipitation in some detail, primarily because they have direct implications for glacial mass balances and for long-term water availability outside the wet summer monsoon season. We use daily precipitation data for December-April from the India Meteorological Department stations at Darjeeling (1901-1996) and Gangtok (1985-2014) in the Eastern Himalaya (corresponding to the ULC community) and from Dehradun (1901-2014) in the foothills of the Western Himalaya (corresponding to the UM community) to detect precipitation trends for each month (see Appendix 4D for details), which are compared with corresponding community narratives of change.

(i) Trends from the ***Eastern Himalaya*** *(reference stations relevant to the ULC community)*

Darjeeling (1901-1996; see Appendix 4D.1) and Gangtok (1985-2014; see Appendices 4D.1, 4D.2)

An analysis of daily winter precipitation data using the Mann-Kendall test reveals somewhat significant ($0.05<p\leq0.1$) declines in total monthly precipitation for December, January, and February over the period

1985-2014 in Gangtok. This points to a tendency in the past three decades towards drier winters, which, coupled with wintertime warming (already discussed in Section 4.1.1; see also Sharma and Shrestha 2016), explains the fact that 100% of ULC interviewees report snowfall to have significantly in recent decades. Local instrumental snowfall records are not available for ULC, and the two reference stations receive only very small proportions of their winter precipitation as snow due to their relatively low altitudes; however, it can be assumed for the high-altitude ULC community that the reduced amounts of precipitation it receives fall in even more reduced amounts as snow (owing to phase changes to sleet or liquid rain) under the influence of recent climate warming, which is seen in the region to be the greatest at the highest elevations and in the December-February winter season (Yan and Liu 2014, Shrestha and Devkota 2010).

In addition to the above data from Gangtok, there are trends from Darjeeling that provide some evidence of drying in late winter and early spring over a longer timescale. Highly ($0.001<p\leq0.01$) and moderately ($0.01<p\leq0.05$) significant declines are seen, respectively, also in total monthly precipitation and mean daily precipitation intensity for February over 1901-1996 in Darjeeling. Also, moderately ($0.01<p\leq0.05$) and marginally ($0.05<p\leq0.1$) significant declines are seen, respectively, in both total monthly precipitation and mean daily precipitation intensity for March over the same centurial period.

The octogenarian Grandpa Tāshī remarks:

> *"When I was a young lad like you, a relatively less snowy winter was regarded as a great blessing, but now we get such little snow that we want to celebrate each time there is a sprinkling... I miss the blizzards of yore, the* wá-shá *[fox-fur-hatted] belles and their snow-bitten cheeks!"*

Grandpa Lobsáng, who is only slightly younger than Tāshī, also concurs but does not seem to miss "the blizzards of yore":

> *"When we were young, snowstorms and cold winds could be very bad - they would kill dozens of animals at a time. Winters tend to be much milder now – thank goodness for that!"*

Middle-aged Pembā also speaks of changes in snowfall, including those in timing:

> *"Snowfall has declined tremendously since my childhood. We used to get at least five or six feet when I was a boy, but now we don't get more than two feet even in the most generous of winters. Also, heavy snow often doesn't come until springtime, when the warmth of the sun makes it very watery. When I was little, we used to have much more snow in December and January - that is the kind of snow that doesn't die soon."*

The latter half of Pembā's remark reflects the ULC community's unanimous concern that the peak of snowfall has shifted from early winter towards spring in recent decades, resulting in shallower and shorter-lived snow packs. A related observation made by the vast majority of ULC interviewees is that unusually prolonged spells of unusually heavy rain as well as unseasonal snowfall events have become more frequent in April over the past few decades. This is congruent with Rathore et al.'s (India Meteorological Department, 2013) report of a statistically significant ($p\leq0.05$) increase of 35.1 mm a^{-1} in

April precipitation for Sikkim over the period 1951-2010. It is also congruent with our primary analysis for Gangtok over 1985-2014, which reveals that April has seen statistically insignificant ($p>0.1$) but non-negligible increasing trends in both total monthly precipitation and mean daily precipitation intensity, a moderately significant ($0.01<p\leq0.05$) rising trend in the number of days with precipitation ≥80th percentile, and a marginally significant ($0.05<p\leq0.1$) rising trend in the number of days with precipitation ≥90th percentile.

(ii) Trends from the ***Western Himalaya*** *(reference station relevant to the UM community)*

Dehradun (1901-2014; see Appendix 4D.3)

An analysis of daily winter precipitation data using the Mann-Kendall test reveals a marginally significant ($0.05<p\leq0.1$) decline in total monthly precipitation for December, a moderately significant ($0.01<p\leq0.05$) decline in mean daily precipitation intensity for December, and a marginally significant ($0.05<p\leq0.1$) rise in mean daily precipitation intensity for February over 1981-2014 in Dehradun. These trends point to a tendency in recent decades towards early winters becoming drier with less intense precipitation and late winters witnessing more intense precipitation. Local instrumental snowfall records are not available for UM, and Dehradun, which is located in the foothills at an elevation 3,000 metres lower than that of Kédārnāth, receives none of its winter precipitation as snow. However, it can be assumed for UM that the reduced amounts of precipitation it receives fall in even more reduced amounts as snow (owing to phase changes to sleet or liquid rain) under the concurrent influence of rapid climate warming, which is even more pronounced in the winter (see Shrestha et al. 2012).

The above climatological observations resonate with the UM community's (as well as the ULC community's) unanimous concerns about snowfall decline, particularly in early winter, and a shift in the peak of snowfall from early winter towards spring, which is seen to result in shallower and shorter-lived snow packs.

Umāpati, a stately practising priest in his fifties, reminisces about the winters of his childhood:

> "*We would have to cleave the snow… carve passages through it to enter our lodgings… Sometimes the roof would start to collapse under the weight of the snow."*

His colleague Dinésh complains:

> *"When we were in elementary school, there used to be at least ten, twelve, fifteen feet of snow here at the start of the summer pilgrimage season… Now the situation is such that when the temple doors opened on 9th May… there was no such thing as snow... If there isn't already much snow by late January or early February, there is no way even small patches can last until the start of summer."*

Granny Sāvitrī shares a nuanced observation about the timing and quality of snowfall:

> *"Fifty, sixty, seventy years ago… when I was a bubbly lass, we used to have several feet of snow by the beginning of Pausha [early January]. That is the kind [of snow] that can even last until the following winter… it has become very rare now… And it's never as dry and flaky as it used to be… That's because it's too warm now... And the snow that comes around* Holī *[springtime] is even more watery – it can't even stay for two days! Most of the snow we get now comes very late… at the end of Māgha [February] or later… so it's either wet and sticky or mixed with hail-like pellets – it melts quickly and those high ridges become completely bare by early summer."*

A related observation for the longer periods 1901-2014 and 1951-2014 is that statistically significant ($p \leq 0.05$) increases occur in both total monthly precipitation and mean daily precipitation intensity in April, indicating wetting and precipitation intensification in late spring over the past century and half-century. This, along with the similar intensification of April precipitation seen at the Eastern Himalayan station of Gangtok in recent decades, should be examined in relation to recent climate warming-induced changes in the springtime activity of extratropical westerly low pressure systems that are carried by the subtropical jet stream from over the Mediterranean, eastwards across west-central Asia, to the Himalayas (see Madhura et al. 2015).

4.1.2.2. Projections of precipitation change

Available national-scale precipitation change projections for India, regional-scale projections for the Hindu Kush-Himalaya (HKH) mountain system and its various segments (with the Western and Central Himalaya corresponding to the UM community and the Eastern and Central Himalaya corresponding to the ULC community), and sub-regional-scale projections for the Indian provinces of Uttarakhand (corresponding to UM) and Sikkim (corresponding to ULC) as well as relevant districts and individual gridded model output cells within each of these provinces were reviewed (see Appendix 4B.2 for details). Overall, the level of confidence in regional precipitation change projections, especially over the Central Himalaya (at whose western and eastern ends, respectively, the UM and ULC communities are located), is low as a result of relatively high model uncertainty and poor consensus among downscaled regional climate models (Sanjay et al. 2017). However, for both communities, the general tendencies are towards at least slight drying in the December-February winter season and at least slight wetting with greater high-intensity extremes in the June-September summer monsoon season. For example, Sanjay et al. (2017) project for the Central Himalayan region an 8.8% fall in winter precipitation and a 19.1% rise in summer monsoon precipitation (CORDEX multi-RCM ensemble mean) for 2066-2095 relative to 1976-2005 under RCP 8.5, the steepest of the four greenhouse gas concentration trajectories defined in the IPCC's fifth assessment report. Also, Wu et al. (2017) project for the entire Hindu Kush-Himalayan region (over the same period under the same greenhouse gas concentration pathway) a 57.8% increase in precipitation received annually as amounts equalling or exceeding the 95th percentile of wet-day precipitation (CMIP 21-model ensemble mean). These projections resonate with community observations of strong tendencies towards more extreme summer monsoon precipitation and winter snowfall declines and in both study regions.

4.1.3. Summary of climatic changes

The key climatic changes facing the Eastern Himalayan ULC community are found to be as follows:

(i) The regional climate has become warmer over the past half century (at 0.2-0.5°C per decade), with the steepest temperature increases (0.4-0.7°C per decade) observed at the highest elevations (>4,000 m) and in the winter season. Moreover, regional climate projections indicate annual mean temperature increases of 4°C or more (as well as wintertime warming of 5°C or more) by the 2080s under the RCP 8.5 greenhouse gas concentration pathway and the SRES A1B and SRES A2 emissions scenarios (see Appendices 4A.1, 4A.2). These climatological insights are congruent with community observations of sustained climate warming over the past half century, with the greatest temperature increases felt at the highest elevations and in winter.

(ii) Broadly in consonance with community reports, a likely increase has been climatologically observed in short-spell, high-intensity summer monsoon (June-September) precipitation over the past three decades despite significant drying over the past century (see Section 4.1.2.1.1). Regional climate projections indicate intensification of monsoon precipitation with sharp increases in extremes over the 21st century (see Appendix 4B.2).

(iii) Winter precipitation has declined, coupled with warming over the past three decades; reduced amounts of winter precipitation are presumably falling in even more reduced amounts as snow (owing to phase changes to sleet or liquid rain) under the influence of pronounced wintertime warming, which is the greatest at the highest elevations (see Section 4.1.2.1.2). These climatological observations confirm community reports of a sharp decline in snowfall over the past few decades.

The key climatic changes facing the Western Himalayan UM community are fairly similar to those identified for the ULC community, except that:

(iv) The UM community has been exposed to a considerable climatic shift in the month of June towards a wetter and significantly more extreme regional precipitation regime over the past century and particularly over the past half century.

(v) During the wider June-September summer monsoon season, the UM community's regional climate has undergone some wetting with an increase in extreme precipitation over the past three decades. However, there has been no intensification of precipitation at all (but also no significant drying, unlike for ULC) over the past century or half century (see Section 4.1.2.1.1). Regional climate projections indicate intensification of monsoon precipitation with considerable increases in extremes over the 21st century (see Appendix 4B.2), concomitant with annual mean temperature increases of around 2°C by the 2030s and 4°C or more by the 2080s under the SRES A1B and SRES A2 greenhouse gas emissions scenarios and the RCP 8.5 concentration pathway (see Appendix 4A.2). There is a good match between the above climatological data and the UM community's understanding of its own local climate.

4.2. How do these changes matter?

All interviewees in both the ULC (Sikkim state) and the UM (Uttarakhand state) communities express at least some apprehension about the disruptions they have observed in their local climate regimes over the past few decades. Although the interview data presented so far has already given some sense of the societal dimension of ongoing environmental change, I will use this section to more systematically enumerate the locally perceived implications of specific climatic changes for the communities' physical safety, natural resource base, economic security, and cultural and spiritual heritage.

4.2.1. More extreme monsoon precipitation

The foremost concern among both communities (93% of 30 interviewees in ULC, 100% of 25 in UM) is that increasingly frequent high-intensity monsoon rainfall events are leading to greater slope instability and flooding, which can threaten lives and livelihoods.

Grandpa Lobsáng of ULC remarks:

> *"[I am] not really [bothered] now, but there may be real trouble if summer storms continue to become more violent... Water and soil give us life, but if the sky is angry, it can use them to destroy life."*

Pembā of ULC adds jestingly:

> "*Very heavy rain is a great liberator for the land under our homes and under our feet... If our land goes down, we all go down, our children and yaks go down. If the river goes up, we go down to Bengal, to the home of Mother Kālī [the wrathful Hindu goddess of time, death and destruction, who is very popular across the plains of Bengal] and her Mamatā [lit. 'affection for one's own' or 'maternal love', the name of the female Chief Minister of West Bengal]. By the time my children get old, this may become the norm."*

HKB Harprasād, a middle-aged lodge owner in UM, explains:

> *"Over the past few monsoons, we've really seen the power of the sky... clouds burst and it doesn't just rain – the whole sky comes down and becomes one with the ground... The land flows and sucks your house in too..."*

In recent years, catastrophic impacts of extreme monsoon precipitation events have been recurrently reported from both regions. For instance, in June 2013, at least 4,120 persons died and more than 110,000 had to be rescued after Uttarakhand was ravaged by rainfall-induced flash floods, earth slides, debris flows, and a moraine-dammed lake outburst (PTI 2013, Ramachandran 2013, TNN 2013, Singh et al. 2014). The reconstruction cost for this disaster was estimated at US $661 million (JRDNA Team 2013). In September 2011, when a magnitude 6.9 earthquake ravaged India's Sikkim state, intense monsoon rain contributed significantly to the density and severity of earthquake-induced landslides (DMMC 2012, Chakraborty et al. 2011).

4.2.2. Drier winters

An additional concern in UM is that winter precipitation deficiencies, in conjunction with higher temperatures, contribute to the drying up of mountain springs (92% of 25 interviewees), pre-monsoon water shortages (80%), and heightened forest fire risk in early summer (64%). In the words of Vishnu, who is in his early twenties and sells temple offerings:

> *"Because of the decline in winter snowfall, we have had severe water shortages. Before, they used to say that there is no water scarcity in the mountains. But to say that now would be wrong… because ever since it started not to snow… I mean, even if snow falls, it is too little… So there are acute water shortages before the monsoon… People are put to great trouble… It's May and most of our springs and water sources have dried up… and pilgrims have started arriving in huge numbers... The soil is so dry and temperatures so high that there have been hundreds of forest fires in the lower mountains over the past few weeks…"*

In ULC, which has a wetter climate than UM, there is a similar but less acute concern about drier winters and perennial snow pack and glacier shrinkage; it relates mainly to declining pre-monsoon small-stream discharges (63% of 30 interviewees) and pasture productivity (60%).

Pembā complains:

> *"Snow gives us grass and food. We don't get enough snow anymore. Less snow in the winter means less water in our streams before the rains... It means poorer grass for our yaks and less milk and eventually less meat for us."*

Thekchen explains how he thinks drier winters are making early summer pastures less productive:

> *"Winters have become drier, so snow accumulations over and around high yak pastures are now very thin and short-lived… There is little meltwater in the springtime, so grasses have a tough time coming out of the earth. Even after maturing, they remain poorly watered through the first month of the summer grazing season. That is exactly why grass and milk yields have gone down since my childhood… Well, the monsoon still arrives, and it does make pastures really lush, but it brings so much rain that there aren't enough grazing days for us to recover from the losses of early summer! Early summer grass is crucial to our animals' health because they need good food after the hardships of winter. If our grazing season begins on an unpleasant note, we grumble all summer."*

Karma, whose pastures are nourished by glacial meltwaters, has no complaints about pasture productivity; in fact, she reports a warming-induced acceleration in early summer grass growth:

> *"Our animals spend their winters with the Dokpā people near Cho Lhāmú and summers with us near Sébu Lā at the head of the Lhāshar, where the glaciers end... Despite the decline in winter snowfall, our pastures in the Lhāshar Valley are at least as productive as they used to be - that's because there is more warmth in the air, which makes the grass grow faster and causes the ice beneath the soil to thaw more nicely than before. But ridge pastures must have suffered due to dryness – unlike us, they don't have a direct supply of nectar from the glacier."*

4.2.3. Cultural snowless-ness

About half (53%) of ULC interviewees believe that the ongoing long-term loss of ice and snow is having adverse cultural and spiritual impacts on the community.

Grandpa Tāshī speaks of the moral implications of snowless-ness:

> *"I just feel sad… I feel sorry for my descendants… As the snow disappears and dark rocks appear, so will our innocence disappear and evil appear."*

Pembā is concerned about the future of his community's faith in the bounteous mountains, which is central to traditional eco-spiritualities:

> *"By the time our children grow old, our smaller glaciers might die. If that happens and we don't get much winter snow either, who will feed our little streams before the rains? And if the rains are late, we may not be able to fall back on snow and ice, our Khángchengyáo, our Khángchendzöngā! Will our own mountains let us down one day? That will shatter our faith, break us…"*

Grandpa Lobsáng, a very proud highlander, fears for his descendants' cultural identities in a warming, deglaciating environment, while also acknowledging that those traditional, ecologically rooted identities and the "pristine" lifestyles associated with them are perhaps already under siege from rapid modernisation, which is bringing in "filthy" (perhaps consumerist) social influences from the "yak-less" lowlands (and the more economically developed outside world at large):

> *"We love the warmth, but it's killing our ice and snow. If my great-grandchildren and their yaks have to depend completely on the warm, mucky Bengali rain for water, they will remain Bhutiā only in name. May they never see such terrible times! But will they even be living up here then? Hehe… I suspect they will rot away in a world of filthy yak-less-ness anyway!"*

As is evident from Grandpa Lobsáng's words, the ULC society's concerns about a potential environmentally-induced depletion of traditional cultural values and identities cannot be separated from – and may in fact be a projection of – underlying apprehensions about the ongoing socio-economically induced decline of tradition. It is through such intricate interactions among the natural/geophysical, the psycho-cultural, and the socio-economic that lived experiences of climate change are shaped.

4.3. Why is the climate changing?

I will now go on to examine the nexus of causal explanations, rooted in both material and incorporeal conceptions of the environment, that each of the two communities creates to make sense of the substantial climatic changes it has lived through over the past few decades. In the process of doing so, I will touch upon the culturally moulded ontological positions, moralities and emotionalities that underlie local understandings of environmental dynamics amidst social change. This ethnographic project will continue through Chapters 5 and 6.

4.3.1. Explanations from the ULC community

About half of all ULC interviewees (14 of 30) comment, without being given any prompts, on why they think the local or regional climate has changed. Climate warming is regarded by 10 of the 14 respondents as the fundamental process that generates secondary changes such as increases in extreme precipitation. However, all the causal explanations that the respondents provide are for anomalous, extreme or otherwise unfavourable weather in general, and not for specific observed changes such as warming, snowfall decline, or heightened rainfall intensity. These generic changes are attributed to the following physical factors: (i) heat release from buildings and vehicles, both locally and regionally (9 of 14); (ii) global industrial and vehicular pollution (7 of 14); and (iii) population growth, especially on the plains of Bengal and China (4 of 14). Besides, the following historical events are identified by some respondents as having numinously interfered with atmospheric processes ['the sky'], sometimes in conjunction with the above physical factors, to bring about adverse or "inauspicious" climatic changes: (i) the arrival of the only metalled road in the valley in the early 1980s (4 of 14); (ii) the arrival of the Indian Army in the early 1980s (also, acts of animal cruelty reportedly committed by a few personnel at sacred sites in the mid-1980s) (3 of 14); (iii) the 18 September 2011 earthquake in Sikkim (4 of 14); and (iv) the 26 December 2014 tsunami in the Indian Ocean (3 of 14).

Phuntsok, a young man who boasts of his "sixth sense", explains:

> *"Hot and polluted air from factories and cars is damaging the weather. And how can I not mention the millions of people who live and die in the mess on both sides of our mountains – China, Bengal, all the rest of them! But the real thing, which few people can sense, is that since the 18 September 2011 earthquake, we've had really crazy weather… It has shaken our faith in our traditional Tibetan calendar... We've had more short-lived but huge rainstorms… and monsoon-type landslides at totally wrong times."*

Grandpa Tāshī mumbles:

> *"Ever since the road and the military men and their machines arrived here [1980s], the insanity of the skies has been troubling us. Things are so bad now that if you don't know which month it actually is, you can't guess the season correctly. Winter days can be summery, and summer days can be wintry. If somebody doesn't know today's date, he will think it's January, not October."*

Tsewáng, his middle-aged friend, adds:

> *"There was a storm and a big flash flood at Kalep in 1985 or 1986, where some new Sikh Regiment men had slaughtered a pig, smeared kerosene all over him, and set him on fire to remove his body hair. As soon as the fumes from the burning meat entered the local deity's nostrils, the whole military camp was wiped out… The weather has been treacherous since that night... Also, the weather has become even stranger since the 2004 tsunami. I think the tsunami has polluted our sky… impregnated it with foul rain."*

It is noteworthy how unpleasant memories of individual non-meteorological events are invoked to explain, sometimes moralistically, the locally observed climatic tendency towards more extreme and anomalous weather since the 1980s, and especially since the 2000s. As discussed in Section 4.1.2.1.1, our analysis of daily precipitation data from Gangtok and Mangan in Sikkim does indicate some intensification of monsoon precipitation and a probable increase in short-spell, high-intensity monsoon precipitation in the region over 1985-2014 and 2001-2015 - periods that correspond well (albeit coincidentally or "numinously" rather than by physical causation) with the climatically aberrant or "cursed" post-1980 periods identified by the interviewees. It can be argued that despite their tremendously positive economic impact, modern infrastructure, military bases, mass tourism, and resultant social influences from the lowlands since the 1980s have naturally been disruptive to ULC's previously insular culture, and that is very possibly why these social changes are implicated by some interviewees in the advent of "inauspicious" climatic changes. This draws our attention to the deeper question as to what the ULC community thinks of the impact of social change on its own emotional relationship with the natural environment. We examine the issue in some detail in the following paragraphs.

The recent introduction of modern infrastructure, including the metalled road (early 1980s at Lāchen, late 1980s at Thánggū), hydroelectricity (late 1980s at Lāchen, absent at Thánggū), solar panels (early 2000s at Thánggū and Lāchen), cable television (early 2000s at Lāchen, absent at Thánggū), direct-broadcast satellite television (late 2000s at Lāchen, absent at Thánggū), mobile phone connectivity (mid 2000s at Lāchen, absent at Thánggū), and 3G mobile phone internet (2014 at Lāchen, absent at Thánggū), has greatly reduced the remoteness of the ULC community. Owing to improved connectivity and mobility, exchanges of goods (e.g. electronic goods manufactured in urban India, handicrafts produced by the community), services (e.g. higher education services offered by urban India, tourism and hospitality services offered by the community) and cultural practices with the external world, primarily the rest of India, have grown rapidly. This socio-economic intercourse has ushered in an era of greater material abundance but also of greater dependence on and assimilation into the non-indigenous and the "global". Consequently, livelihoods, relationships with the natural environment, and cultural values have begun to undergo a deep transformation, which is causing the traditional Buddhist transhumant agro-pastoral society to crumble.

The ongoing societal transformation, especially the rapid growth of employment outside farming, is perceived both very favourably (from a modernist rationality-inspired materialist standpoint, especially by 14 of the 30 interviewees, all non-monastic young people and hopeful parents of school-going children) and negatively (from cultural nostalgia-inspired and traditional eco-spiritualist standpoints, especially by 12 of the 30 interviewees, mostly community elders and monks). Often, the same individual simultaneously holds both of these seemingly irreconcilable worldviews at different psychological levels, activating the one that is more situationally adaptive at a given time. Also observed in the UM community, this aspirational dualism in the face of the classic modernity-tradition scrimmage is a recurrent societal theme that Chapter 5 explores in greater depth.

The vast majority of interviewees (25 of 30), including those who at least superficially embrace modernity, do in fact believe that modernisation erodes traditional metaphysical values and increases material entanglement, thereby strengthening the hold of *māyā* (the illusion that makes the material world seem real) on one's consciousness. This belief implies that, as modernity spreads, metaphysical aspirations decline, the 'three fires' of *rāga* (sensory attachment as in lust and greed), *dvésha* (sensory aversion as in hate) and *moha* (delusion) and resultant worldly desires proliferate, and *duhkha* (a pervasive sense of worldly dissatisfaction and suffering) deepens, notwithstanding (and often owing to) the material 'well-being' brought about by economic development.

Unconditional love and compassion are thought to fade away as people's everyday interactions with their own selves, other living beings and nature become deeply entrenched in the material plane of the 'three fires'. Extractive, egotistical human-human and human-environment relationships push communities into downward spirals of heartlessness, conflict and *duhkha*, trammelling those who seek earthly harmony by trying to liberate their consciousness from materiality. Expressing this sentiment, Yángkey, a middle-aged shop owner, grumbles:

> *"Life was pure and peaceful when our people were simple yak herders and all they knew was grass and snow. Now we are becoming like anybody else – selfish, shrewd, sad, and enemies of nature."*

Nearly three quarters of the interviewees (22 of 30) feel afflicted with the sense that the external pressures of development and politics have constrained their ability to develop meaningful and emotionally enriching relationships with their natural environment, shattering the pastoral idyll that some refer to as the "yak world". Impressed with neighbouring Bhutan's apparent success in generating some economic prosperity without indiscriminately destroying traditional rustic cultures (including monarchically-inspired senses of humility, industry and community), natural capital, and eco-spiritualities, most interviewees (17 of 30) express romantic notions about the "blessed reigns" of their own Chögyál (lit. 'righteous monarchs') – an era that came to an abrupt end at the time of Sikkim's merger with India in 1975, as a direct result of which the valley was connected to the Indian road network and steadily militarised. The elderly also reminisce about their "carefree times in windswept yak-lands" before the sealing of the Sikkim-Tibet border in the aftermath of the 1962 Sino-Indian War, and especially before the Chinese invasion of Tibet in 1950-1951. They complain that the lack of mobility imposed by the border has been a major setback to their community's experience of the culturally and spiritually vital boundless vastness of their ancestral "yak-lands". Understandably, all this has led to a resented unfulfilled-ness in the community's emotional bond with its natural environment, which is reflected in some people's tendency to lay the blame for adverse climatic changes on arbitrary factors that seem to threaten traditional ways of life and eco-spiritualities.

4.3.2. Explanations from the UM community

Owing to their still-vivid memories of the 2013 disaster, nearly all UM interviewees (28 of 30) eagerly provide reasons for the changes they have observed in the local and regional climate - primarily warming, but also increased rainfall intensity, snowfall decline, and heightened intraseasonal and interannual temperature and precipitation variability.

All of the 28 individuals who address the attribution question identify warming (without a fixed sense of spatial scale as in "local", "regional", or "global") as the prime cause of all other climatic changes. The vast majority of these respondents (23 of 28) also point to direct links between temperature rise and high-intensity rainfall events or "cloudbursts", explaining them either in largely physical terms or also by means of morally driven supernatural processes. Many of those who directly link extreme precipitation to warming (8 of 23) believe that evaporation from newly constructed dam reservoirs within the region has been playing a role in generating cloudbursts.

Bélā, a retired farmer in her sixties, stares at the sky and yells:

> *"When you [the sky] are warm, the rain is fierce… That is what happened at the time of the disaster… When you get too hot too quickly, you shed too much rain too quickly - that is Nature's law… All our* pāpa *[vice] rises to the sky like invisible flames… Tall, dark clouds rise… Then more clouds are pulled out of the big lakes they've made by stopping our rivers – like the one above Srinagar…"*

Climate warming itself is attributed to different combinations of the following factors: (i) local pollution and heat generation by vehicles, diesel-powered electricity generators and cook stoves (23 of 28); (ii) vibrations and heat from the (nearly 300) continual helicopter sorties each day during the pilgrimage season (20 of 28); (iii) local and regional overpopulation (17 of 28); (iv) regional-scale urban and industrial pollution and heat generation (15 of 28); (v) global overpopulation (9 of 28); (vi) global-scale, especially developed-world, urban and industrial pollution and heat generation (6 of 28); (vii) moral consequences of sensory gratification associated with greed- or lust-driven material consumption, sometimes involving dissipative releases of *tapas*, a non-physical heat-like energy (6 of 28); and (viii) correctable chemical imbalances in the "sky" or atmosphere (3 of 28).

The priest Dinésh provides the following explanation, which incorporates multiple *physical* causal processes:

> *"I think "global warning" [sic] is happening, or there is more heat in the environment, or something is having an effect on the environment – there must be something or the other… The thing about the environment is that the population has grown… or that we did not have any generators here before… as fuel, we only used firewood back then… and there were fewer pilgrims. Now there are many more pilgrims… So perhaps that's why the climate here… the temperature would have gone up… But most importantly, these helicopters have disrupted our whole climate system... Has there been even a five-minute pause in their noise since sunrise? This is a major reason for all the bad weather we have had in recent years…"*

Dinésh's priest friend Umāpati confidently lays the blame on helicopters alone. (Coincidentally, he has lost business due to helicopters because pilgrims who fly into Kédārnāth usually fly out the same day and therefore do not need to stay overnight at his lodge.)

> *"Since when has there been a major change? Since the arrival of the helicopter service… That has had a tremendous impact on the weather… As far as I know… generally speaking, the disaster that happened in Kédārnāth, the glaciers that burst, and all the rest of it… all of it happened because of the helicopters… Before, people used to trek to the temple… sticks in their hands, nothing else. Today, all these helicopters that are flying… it is because of these that the whole weather system… There is a huge impact on the environment… and that's why the whole system is collapsing."*

The lodge caretaker Jagdīsh has a different view, which comes very close to the "Western scientific" consensus on the anthropogenically enhanced greenhouse gas effect; he focuses on "pollution" caused by heightened living standards and consumption levels, not only within the region, but globally and particularly in the developed world:

> *"No, how can a few helicopters change the weather? It's just that there is so much pollution now… When we were little, cars were seen very rarely. But now everyone has* gārī-ghorā *[material comforts, lit. 'car-and-horse'] and everything. That's what makes all the difference. Before, there was nothing here. Now there are even small companies. They pollute the environment… When the weather in Kédārnāth is changing, weather patterns must be changing all over the world… Everywhere, because of pollution… Look at foreign countries' cars, motors, etc… big, huge corporations – their pollution also affects the weather… All these things harm the air."*

Mahésh, a seasonal taxi driver in his thirties, concurs, adding to Jagdīsh's explanation a sharper sense of differentiated responsibility, i.e. wealthier and more urban populations being significantly greater contributors to the problem:

> "*I think it's the pollution from the cities… It's because of rich people… cars, air conditioners…"*

Young Vishnu also identifies population growth as a key factor:

> *"Pollution causes it. I know it. We learnt all this at school. But the other big thing is population growth... Look at all these crowds of pilgrims!"*

Sunītā, a young housewife and cattle herder, remarks amusedly:

> "*I think there are just too many people – breathing, eating, defecating, travelling, sinning, destroying nature… Haha, and too many cars and cattle… Perhaps that's why there is more heat, more storms, less snow."*

Note that both cars (carbon dioxide) and cattle (methane) are sources of greenhouse gas emissions.

Then there is also Granny Champā's impassioned explanation, which has an additional moral dimension that relates to the *karmic* (merited-according-to-past-actions) effects of excessive consumptive activity and consumerism (see Chapter 5 for a detailed discussion on *karma*):

> *"Rain, snow, clouds… everything has changed so much because the sky is getting too hot! It's getting hot because there are so many people and so many big things and cars and machines doing their nonsense… Fancy clothes,*

fancy food, fancy boxes… you don't need any of it, and it's garbage anyway… Fools, the more stuff you buy, the more pāpa *[bad* karma*, vice] you will accumulate… and that will generate heat in the air… storms, loss, suffering, grief... Control your senses! Live a simple, thoughtful life amidst nature, as my husband did… Sit quietly by the river, teach yourselves* tapasyā *[unwavering meditation], and build up* tap *[meditative heat in esoteric yogic practices] within yourself… rather than squandering it all away to wreak havoc."*

Ravi, a well-dressed schoolmaster and shopkeeper in his thirties, firmly dismisses Granny Champā's reasoning as superstition. He argues:

"Stop putting the blame on the way we live… All this is happening because of a chemical problem. The sky has too much of something, or too little… Surely we can add or remove those things from the air? If I were a scientist…"

Granny Champā retorts:

"Take this smart lad away to Delhi, Bombay, Dubai, America!"

Although Granny Champā's explanation does not seem to be based entirely on physical causation, the connection it makes between climate warming and consumerist lifestyles fuelled by high energy consumption is insightful and arguably indicative of a sense of environmental responsibility inspired by traditional eco-spiritual values such as austerity and nature-based contemplation. Ravi's contrasting modernist-rationalist outlook, which makes him dismissive of Granny Champā's "mumbo jumbo" and curious about the possibility of a technological fix, may be reflective of wider cultural changes in the region.

Apart from the large and ever-increasing seasonal influx of pilgrims into the UM valley, recent improvements in transport and communication connectivity (rural road network expansions, direct-broadcast satellite television, and 3G and 4G mobile phone services with Internet) and educational access are exponentially reducing the remoteness of the region and bringing in economic opportunity and abundance. Consequently, social institutions, practices and livelihoods are undergoing an unprecedented transformation; agro-pastoral rusticity, ascetic priestliness, and nature-inspired spirituality are, according to most interviewees, being replaced by mass tourism-driven mercantile urbanness, mundane (and often commercially contrived and perfunctory) religiosity, and emotional disengagement from (and disregard for) the natural environment. This "cutting of the umbilical cord" is characteristic, according to some, of more materially absorbed lowland societies. In fact, the vast majority of interviewees (26 of 30) believe that modernisation blights traditional virtuousness (primarily austerity, piety and nobility) and replaces it with vicious materialism - as economic development creeps up the mountains, it progressively perverts the minds of naïve, "morally vulnerable" young people by relentlessly "foisting" endless material comforts on them and distancing them from their roots in the "mountains, rivers and forests". This makes the interplay between endemic highland tradition and invasive lowland modernity a key theme in examining the community's understanding of its changing environment.

4.4. Conclusion

This chapter uses a cross-disciplinary framework to explore two remote High Himalayan communities' experiences of climatic change, especially in the context of extreme precipitation. In developing a holistic understanding of how the communities' local and regional climates have changed over the past few decades, it combines inferences derived from instrumental observations and model projections with qualitative local narratives of change, putting physical scientific data into the context of culture and ethnographic data into the context of climatology. This integrative "two-eyed" view of climatic change (Ford et al. 2016) reflects the dissertation's wider commitment to a pluralist epistemology (see Section 2.1.2).

Climatological and social insights are found to be in broad agreement that both communities are witnessing, overall, a climatic tendency towards higher temperatures, lower snowfall, and greater extremes in monsoon precipitation – a set of conditions that can be expected to intensify the combined hazard of thermally induced geomorphic destabilisation, deglaciation-linked meltwater accumulation, and rainfall-triggered landsliding and flash flooding in high-mountain environments. The implications of these changes for each community in terms of disaster risk are examined in Chapter 5.

The latter half of the chapter shows that the communities express complex and varied physical and metaphysical understandings of why the climate is changing and how it matters to them. The range of worldviews reflected in their explanations is indicative of a fascinating interplay between the cultural forces of tradition and modernity amidst rapid social change – a critical theme that comes to the fore in the discussion of risk and adaptive capacity in Chapters 5 and 6.

5. Examining imaginations of hazards

This chapter examines ethnographically the Upper Lāchen Chú (ULC) and the Upper Mandākinī (UM) communities' understandings, both physical and incorporeal, of the climate-related geophysical hazards that operate in their changing environments. It also spatially contextualises those local understandings, drawing upon my own geomorphological observations in the field, supported by terrain photography and mapping, participatory visual representations of folkloristic models of the physical landscape, and reviews of published geophysical risk assessments.

The climatological evidence and local community observations presented in the previous chapter point to a climatic tendency towards warming, snowfall decline, and greater extremes in monsoon precipitation, which is likely to intensify the multiple interacting hazards associated with thermally induced glacial and periglacial geomorphic destabilisation, deglaciation-linked meltwater accumulation, and rainfall-triggered landsliding and flash flooding in both communities' environments (see, for example, Richardson and Reynolds 2000, Clague and O'Connor 2015, Clague and Evans 2000, Walder and Driedger 1995, Warburton and Fenn 1994, Petley et al. 2010, Petley 2012). What follows is an exploration and appraisal of local ontologies of these geohazards as well as local conceptions of landscape dynamics, which seem embedded in geographically referenced folkloristic expressions of traditional metaphysical principles. The place-based ethnography also immerses itself in the deep psycho-cultural dimension of indigenous geographical knowledges that transcends the materiality of the environment and the hazards that exist in it.

Through this culturally nuanced and geomorphologically corroborated emic anthropological exposition of climate change-related geohazards, the dissertation endeavours to give voice to indigenous metaphysicalities, which have been conspicuously overlooked in geographical studies of environmental risk despite their immense psycho-cultural influence over everyday practices in traditional societies (see, for example, Dueck and Byron 2018). This may in turn contribute to the emergence of more indigenously sourced, and therefore more context-specific and practically useful, epistemologies of risk management, arguably benefitting disaster reduction, climate change adaptation, and the wider practice of development among the two Himalayan case study communities as well as in similar settings across the Global South (see Ford et al. 2016).

5.1. Metaphysical backdrop

Although ethnically distinct and located nearly 1,000 kilometres apart, the ULC and UM communities are united in their foundational ontologies of the dynamics of nature. Both understand environmental hazards in terms of earthly processes as well as the non-physical machinery of *karma* that is believed to underlie them; the physical and the ethereal often come together in geographical legends that are concerned with moralisation.

Karma (lit. deed, action), a behaviourally influential philosophical theme in both the Sino-Tibetan Buddhist ULC and the Indo-Aryan Hindu UM communities as well as across much of Indian society (see, for example, Karnik and Suri 1995, Omprakash 1989), is a doctrine of moral causality whereby people's worldly destinies are shaped by their own intent and actions. Good intent and actions, performed in the light of *dharma* (righteousness, virtue), generate *punya* (merit, good karma), which cumulatively leads to *sukha* (happiness); bad intent and actions, performed in the darkness of *adharma* (immorality, vice), generate *pāpa* (demerit, sin, bad karma), which cumulatively leads to *duhkha* (sorrow, suffering); the common proverb "As you sow, so shall you reap!" expresses the same principle. The *phala* (fruit, result) of a current thought, word or deed arises from a *bīja* (seed) that was sown in the consciousness in the past, either in the present life or in a previous one – a seed of virtue matures into good intent and actions, which bear morally good, happiness-giving fruits in the future, not only in the present life but also in future ones. Conversely, a seed of vice ultimately yields unhappiness-giving fruits.

The nature and quality of a sentient being's current life is regarded as a function of all the karma cumulatively generated over past lives, to which the karma of the current life is continuously being added to determine the being's next rebirth in the recursive loop of *samsāra*, the illusory world we live and die in. Karmic causation also entails the accretion of *samskāra* or deep impressions and dispositions, both good and bad, which condition the actor's consciousness, affecting that individual's capacity for future worldly action and future experiences of *sukha* and *duhkha,* both in the current life and in any future ones. "Fortunes" and "misfortunes" in a person's current worldly life may therefore be attributed to *samskāra* being carried over as karmic baggage from a previous life if no reasonable present-life karmic explanations are found. The responsibility for the occurrence of what would otherwise be regarded as a "chance event" beyond the affected beings' control may then be karmically placed on their moral consciousness.

Despite rapid economic development and social modernisation over the past half century, the traditional karmic mode of causality remains psycho-culturally entrenched throughout both the ULC and the UM communities. Nonetheless, the intrusion of materialist rationality and consumerist and urbanist aspirations, particularly via modern education and mass media, has certainly superimposed a more purely physical and amoral understanding of environmental causality over the bedrock of traditional transcendental metaphysics. The extent to which this superimposition has taken place varies greatly within each community, but in hardly any of the interviewees does it seem to have reduced the behavioural potency of the karmic doctrine. Young and middle-aged non-hermetic men, who are generally the most exposed to external modernising cultural influences, do indeed tend to embrace materialist worldviews, including Western science, with much greater confidence than the rest of the population, albeit only to outwardly supplement rather than to supplant their core metaphysical beliefs, which tend to be repeatedly reinforced by natural calamities that require them to make sense of worldly loss and suffering. Arguably, this functional reconciliation between the seemingly conflicting forces of traditional spirituality and modern materiality is an adaptive psychological response to change, both social and environmental.

The particularly prominent role of karmic causation in the communities' traditional conceptual models of divinely administered landscape dynamics (e.g. collective greed being the root cause of an extreme precipitation event that leads to a debris flow disaster) evokes in the communities' collective consciousness a strong sense of moral responsibility towards the natural environment (see also Crosby's (2008) account of Sri Lankan Buddhists' karmic interpretations of the 2004 tsunami disaster). As we find later in the chapter, this ultimately implies that the communities consider contemporary geophysical processes and resultant hazards to be significantly anthropogenic and responsive to the unprecedented material growth brought about by consumerist modernisation. Although the communities' indigenous understanding of consumptive vice as the root cause of environmental degradation is somewhat congruent with the Western scientific discourse on environmental sustainability, the causal mechanism involved is fundamentally different. Whereas Western scientific causation operates in the realm of physical reality, karmic ontologies transcend material processes and use moral consciousness as the causal medium through which non-physical "impulses" travel from a physical cause to its physical effect. It is generally through traditional geographical allegories, which are full of esoteric allusions, that causal connections are established between the moral and the geophysical.

5.2. Insights from the Upper Lāchen Chú Valley

The ULC community is abundantly aware of precipitation-triggered geophysical hazards such as landslides and flash floods, including those that involve sudden extreme discharges from glacial lakes loosely dammed by moraines. A significant part of this awareness comes through the community's Nyingmā Buddhist-animist folklore, in which geophysical entities are often personified. It is only by engaging with local geographical legends that insight can be gained into the deep, behaviourally potent cultural meanings that underlie the community's everyday experiences of the physical environment, including the hazards present in it.

The most widely invoked of such legends is that of the 8th-century Buddhist sage Guru Rinpochë's (formally, *Padmasambhava*, meaning 'born of the lotus') quest for the *beyul* or 'hidden lands' (a term associated with Sikkim's medieval name, Beyul Demadzong, meaning 'the hidden valley of rice'). The predominant local version of this story, constructed from nine male interviewees' spatially referenced accounts, is as follows (see Figs. 5.1-5.4):

> After completing a mystical mission in Tibet, Guru Rinpochë, along with his retinue of disciples, arrives in and blesses the snowy highlands of present-day North Sikkim. Here, he sows many seeds of virtue and hides many sacred teachings that are esoterically embodied in treasures known as *térma*. He exorcises many demons and appoints them to the role of *nyedág chösung* or 'guardians of sacred places and defenders of righteousness'. Upon entering the region from the direction of the sin-extinguishing site of Chorten Nyīmā (north), Guru Rinpochë flicks a stone across the valley to test the auspiciousness of the landscape. The stone hits the foot of the Khángchengyáo mountain and swells into an enormous boulder (a present-day sacred site shown in Fig 5.1). The expansive blessed lake of Guru-dongmā, 'the teacher and the pioneer', emerges at this site, just northeast of Khángchengyáo. According to another account, Guru Rinpochë arrives in the region via Kyītháng, 'the happy plain' blessed with his footprint, and takes the form of Guru-drágmār or Guru-dong-mār, 'the red-faced teacher', to overcome a wrathful spirit at whom he hurls his *vajra* or indestructible thunderbolt weapon. After blinding the wrathful spirit, the thunderbolt lands at the site of the present-day sacred boulder, and the blessed lake of Gurudongmār comes into being. The nearby Khángchengyáo mountain (6,889 m) either embodies or houses that thunderbolt-subdued, purified spirit. It is sacred in that Guru Rinpochë has made it the local protector of morality (by blessing it with retributive powers, which can generate extreme geophysical events) and the custodian of the landscape, especially the Gurudongmār Lake and several other scattered waters (glacial lakes and meltwater pools – 108 in all, which represents the auspicious number of beads in a Tibetan Buddhist rosary), including the 'female', moraine-dammed Shākā Cho on its southern side (which is located upstream of the community at Thánggū). All streams (including the Lhāshar Chú – Jāchú River at Thánggū) that emanate from these blessed pools are to be regarded as *dütsi*, the death-conquering elixir. Kháng-chen-dzö-ngā (Kangchenjunga, 8586 m; literally, 'the great snows of five hidden treasures'), a lofty mountain not far away, is made the supreme guardian of the wider landscape (of present-day Sikkim and Darjeeling) and is to be regarded as supremely sacred.

With legendary spiritual treasures hidden beneath mountainsides and immortality-giving (read: invulnerability-inducing) meltwaters scattered all over them, the glacierised Khángchengyáo landscape has been accorded sacred status with a central role in the community's mystical model of geophysical dynamics. Glacial lakes, in particular, evoke in the community a numinous sense of quiet, humbling awe. Consequently, local glacier-related hydro-geomorphic hazards, such as the widely known possibility of a catastrophic glacial lake outburst flood (GLOF) and debris flow from Shākā Cho, tend to be perceived not only as undesirable sources of material (including bodily) loss but also as enigmatic sources of transcendental insight into otherwise obscure metaphysicalities (see Table 5.1).

Granny Rinchen, a retired herdswoman in her eighties, expresses great faith in the noble intentions of the *dütsi* or ambrosia contained in Shākā Cho, which is carried to her doorstep in Thánggū by the "diligent" Jāchú River. She conceives of the local hydro-geomorphic system as a conscious and inherently good and just supra-organism, ethicising its interactions with her community by making it a moral medium through which the law of karma operates:

"Till the age of eighteen, I used to spend my summers with my parents and yaks in the Lhāshar Valley, not far from Shāká Cho. People say the lake will burst one day, but there's water peacefully flowing out from underneath the debris [moraine]… That water is dütsi *[the nectar of immortality]… I believe in its goodness; I don't think such holy water will want to smash the debris and kill us… unless that is what we truly deserve… the fate that our past deeds have earned! Like Shāká Cho, Shärabū Cho also swallows ice blocks that collapse from the mountains, but it is too young and shallow to be a real threat. And the tender Youlhá Khángtsá does not even have water; it is just snow."*

Middle-aged Pembā presents another karmic, but much more humanised, conception of landscape processes, which arises from the many geographically referenced folktales he heard from his "wise elders" decades ago:

"I've never seen a destructive flood here, but the Jāchú River becomes rather aggressive in the monsoon. It even comes into our backyard. And when the bridge rattles in the middle of the night, we know that it's time to leave the house and run uphill - towards the monastery and the ITBP camp. But by the grace of Guru Rinpochë, our house has never been damaged… There are three lakes up there - Shāká Cho, Youlhá Khángtsá, and Shärabū Cho. Shāká Cho is very big and deep. I have seen her. She's sitting in Khángchengyáo's lap, just above our yak pastures. She's tilting the lap towards us because she wants to leap out and come to us. But, by the grace of Guru Rinpochë, Khángchengyáo holds her back. Khángchengyáo likes to feed her ice. Every now and then, a huge chunk of ice plunges into the water, making a thunderous sound and sending ripples, even waves, right across the lake. Our wise elders have told us that the benevolent Khángchengyáo will hold Shāká Cho in his lap only as long as we maintain an atmosphere of piety through our thoughts and actions… I think Shāká Cho will surely come down one day, but I can't say when… You see, karma acts through the sky, the earth, everything… If human beings mindlessly keep on eating into nature to satiate the endless urges of their senses… and they are foolish enough to forget that they themselves are part of nature… they will really be eating into themselves, into their own survival, happiness and freedom! These disasters are fruits of our own karma."

By imagining Shāká Cho as a restless girl sitting in the lap of Khángchengyáo, a caring father figure who nourishes her and promises to hold her back until the time is ripe for her to leave him, Pembā and his elders ascribe to the mountain regulatory powers over the operation of the law of karma via the lake. It is the influence of the collective bad karma generated by the community that makes the lake want to "leap out" by tilting the mountain's lap outwards and that of good karma that makes the mountain restrain the lake. Just as atmospheric ("sky") and geological ("earth") forces govern the interactions between the mountain (including the glacier, scree slopes and moraines that descend into the lake) and the lakewaters on the earthly plane, karmic forces are thought to control them on some ethereal plane. In fact, potentially destructive natural events such as high-intensity precipitation, floods and landslides are regarded as physical manifestations of essentially karmic causation. Karma is invoked also to make a more universal point about the inseparability of human consumptive activity from environmental dynamics, which places the moral responsibility for natural disasters collectively on appetitively driven human beings who "eat into themselves" by insatiably "eating into nature", both in terms of environmental sustainability and in the context of spiritual well-being.

Shifting the emphasis away from human responsibility, Dorjë, a high-ranking *lāmā* (monastic teacher) in his seventies, underlines the guardian mountain Khángchengyáo's divinely appointed agency:

"Khángchengyáo has been made so powerful by Guru Rinpochë that he can end war, disease and famine. But if he is not happy with us, he may decide to destroy us. And that is when Shāká Cho will be freed and sent to us… For nearly thirty years, people have been saying that Shāká Cho is about to come down... We are still waiting for the divine command."

Grandpa Tāshī reiterates that the superior gods and the subordinate landform may have conflicting desires, but it is ultimately the gods' will that prevails:

"I have been hearing since my childhood that Shāká Cho will come down one day… that she will explode and her water will take us away. But that has not happened yet because the gods have not wanted it to happen. The lake has tilted herself very sharply towards us, and she aspires to come to us despite her attachment to Khángchengyáo, of whom she was born. But the gods won't let her come… until that is what they want. I can't say when the tussle will end… Shärabū Cho is another one like Shāká, but she is much smaller and not as eager to leave her home. Whatever happens to them and to us will be the will of the gods."

Grandpa Tāshi goes on to explain that the will of the gods is not autonomous - it is determined by the fruits of the affected beings' collective karma; however, if earnest prayers and other atonement efforts are made with a truly pure heart, it becomes possible for the gods to grant offsetting boons of exceptionally good karma that may cause the course of life (or destiny) to circumvent *duhkha*-causing karmic effects. "The great secret is that even deities and demons are creations of karma," he adds, highlighting the paramountcy of karma and the ultimately atheist metaphysics that seems to underlie it.

Remarkably, the ULC community also shows sophisticated *physical* understandings of the Shāká Cho GLOF hazard, which operate in unison with the folkloristically embodied karmic consciousness examined above. Based on years or decades of lived experience, this local geographical knowledge (albeit not necessarily the underlying metaphysics) is epistemically compatible, comparable, and in fact fairly congruent with Western scientific geotechnical hazard assessments, both in terms of its appreciation of landscape dynamics and as a resource for practical disaster reduction. A few purely physical process-based (rather than metaphysical) appraisals of the hazard made by the local community are presented below. These are then placed into the context of geoscience.

Middle-aged Thekchen, who lives by the Jāchú River, is convinced of the inevitability of a flash flood from Shāká Cho, which, he thinks, may be initiated by a monsoon rainfall-induced landslide (rather than a snow avalanche) making its way into the lake:

"Mark my words: Shāká Cho will *come down sooner or later…. I spent many of my childhood summers around Shāká Cho, so I know it is really dangerous… In those days, we used to think an avalanche would push Shāká Cho out of Khángchengyáo's lap, but there isn't enough snow anymore. What will happen now is that a monsoon storm will suddenly throw all of that stony garbage right into the soup bowl, and the soup will go "boom"! Hahaha, and we'll go "zoom"!"*

Dāwā, a herdsman in his sixties, concurs rather prophetically:

"Shākā Cho will explode! It will happen during a monsoon storm. Mud, stones and water will come down like a fire on kerosene… When we are on our pastures in the Lhāshar Valley, we do feel threatened by rainstorms… We are completely exposed because there aren't any trees, bushes, or proper houses there... I lost six strong, healthy yaks in a slushy, muddy avalanche seven years ago between Dambāché and Minbólung. It was September - three months of monsoon rain and sleet had made the earth and snow so gooey…."

Despite expressing unequivocal concern over the possibility of large-scale destruction, both Thekchen and Dāwā speak of the GLOF hazard with almost breathless eagerness, smiling somewhat triumphantly afterwards. While discussing vulnerability in Chapter 8, we follow on from this observation to examine whether there exists deep within some people's minds a parallel and arguably perverse aspiration – to experience extreme, life-threatening geophysical phenomena as some sort of emancipatory escape to extramundaneity, perhaps a spiritual adventure.

Chöjor, another seasoned herdsman in his sixties, makes a more meticulous, conservative, and noticeably unfrenzied assessment of the GLOF threat, providing geomorphological details such as potential triggers for a lake outburst (high-intensity rainfall or an earthquake acting in conjunction with heavy rainfall), moraine dam freeboard in different seasons (only a few feet during the summer monsoon), and the normal mode of discharge from the lake (piping):

"I was with my yaks in the Lhāshar Valley until a few days ago. I have spent nearly every summer there since the age of seven or eight. Shākā Cho is a large lake - it can cause a lot of damage if it bursts, but that is possible only if there is a huge cloudburst or an earthquake amidst heavy rain… something on an extraordinary scale… If you look at the debris wall [moraine] from below, you will be convinced that it can collapse any moment… You'll run away! But if you stand on the crest [of the moraine], it doesn't seem very scary. The water remains a few feet below the crest even in the rainy season, and leaks out very slowly and steadily from underneath the debris. And in this dry season, the water level can be more than 10 feet lower than the lowest point on the crest. Also, the debris seems quite stable, at least when it is not too wet… I think an overflow is unlikely, but the lake can explode if the whole wall [moraine] crumbles."

Jinpā, another herdsman from the same valley, eagerly adds to Chöjor's account his own "expert" observations on the stability of the moraine that dams Shākā Cho, referring to it as seemingly strong but "just a heap of loose debris and not a cemented fortress". He also ebulliently elucidates the fear surrounding Shākā Cho:

"Every summer, from May until September, at least nine or ten families live in the upper reaches of the Jāchú-Lhāshar Valley with their yaks. Our summer pasture is just below Shākā Cho. Our elders have been saying that Shākā Cho will burst one day, but I think the wall [the moraine that dams the lake] is quite strong… But we do get frightened when it rains a lot… After all, it is just a heap of loose debris and not a cemented fortress! The 2011 earthquake happened in the rainy season, when the lake was full and the debris wall pretty oozy… When the ground started shaking, we didn't think it was an earthquake - we were sure that Shākā Cho had finally exploded and the end of Lhāshar and Thánggū was near… Somebody shrieked, "Run! Run! Run!" Our yaks ran in different directions - some uphill, away from the stream… others towards it. Haha, it was great fun!"

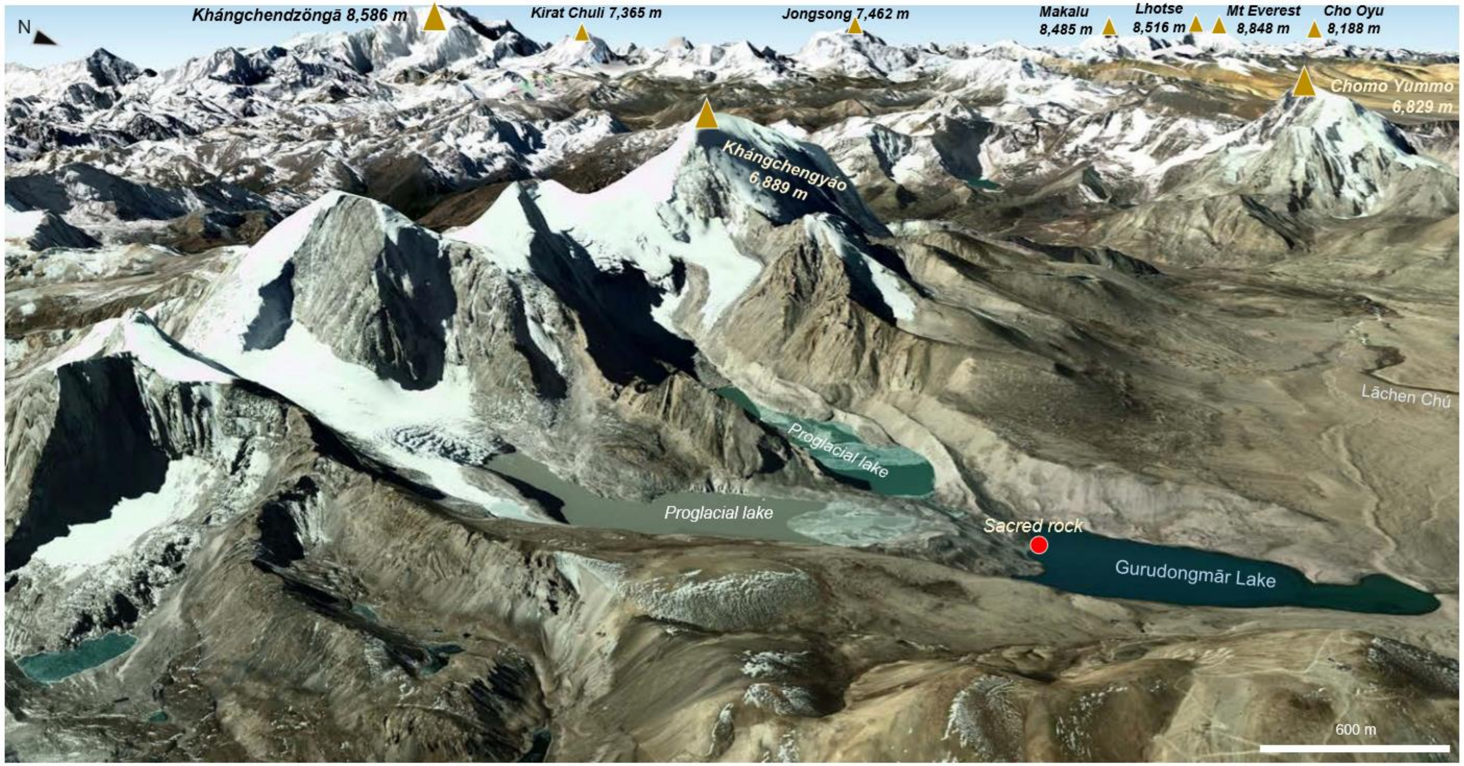


Fig. 5.1. *TOP:* Google Earth image (© 2018 CNES/Airbus, © 2018 DigitalGlobe): looking southwest from over the Tibetan Plateau towards the northeast face of the Khángchengyáo massif and the proglacial lakes of Gurudongmār; *TOP RIGHT:* a visual representation of local elders' spatial conception of the north face (Tibetan Plateau side) of the holy Khángchengyáo massif, Gurudongmār and some of the other "108 blessed waters", and a mound of esoterically hidden *térma* treasures; *LEFT:* a photograph (credit: Vaibhav Kaul, 2015) of the prayer flag-adorned sacred rock at the upstream end of Gurudongmār Lake (shown as a red dot on the Google Earth image and as a black dot on the traditional sketch above), which is believed to a legendary stone flicked by Guru Rinpochë to test the auspiciousness of the landscape

Fig. 5.2. Google Earth image (© 2018 CNES/Airbus, © 2018 DigitalGlobe): looking southwest from over the Tibetan Plateau towards the headwaters of the Lāchen Chú River, the northeast face of the Khángchengyáo massif, and the glacial lakes of Khángchung Cho, Cho Lhāmú and Gurudongmār, with the Lhāshar Chú – Jāchú River joining the Lāchen Chú at Thánggū

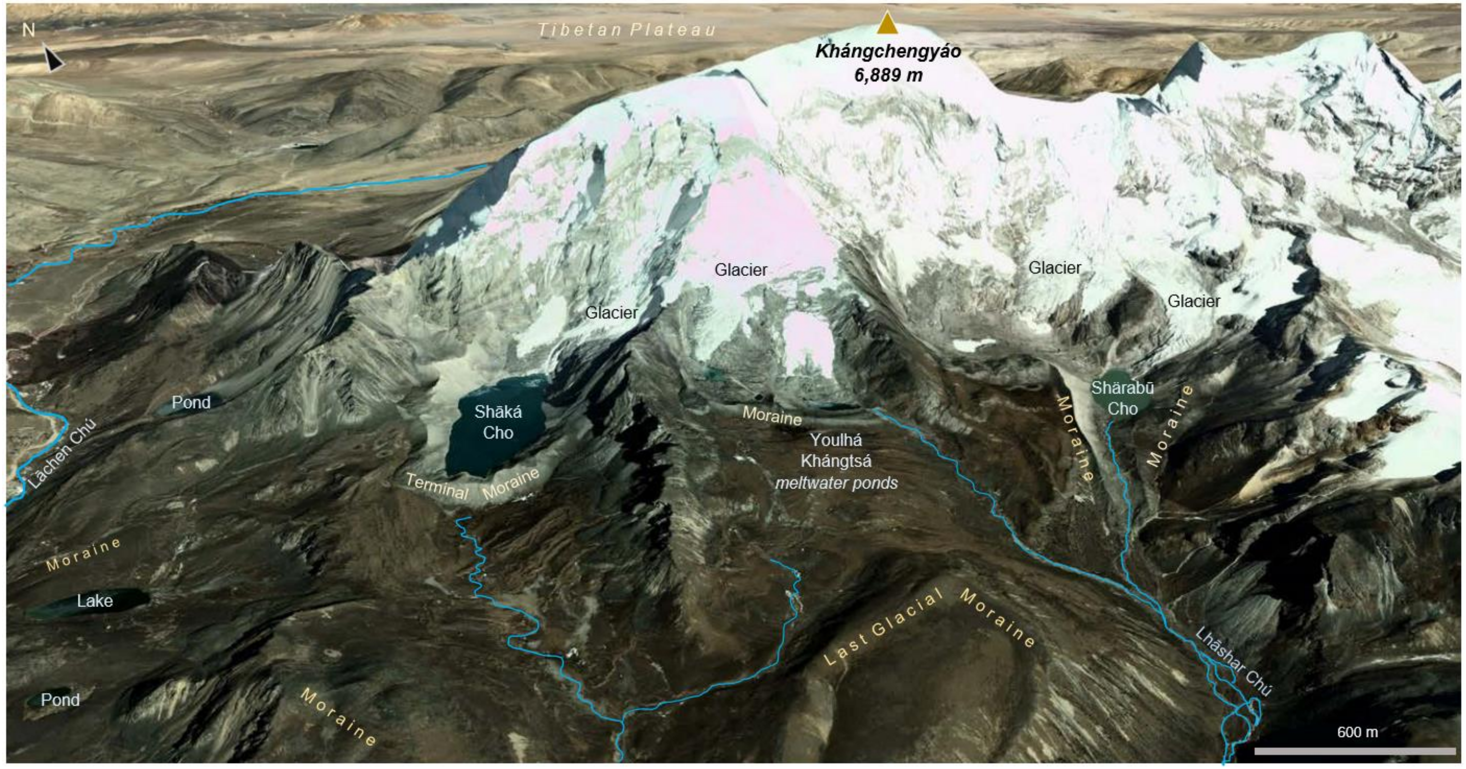


Fig. 5.3. *TOP:* Google Earth image (© 2018 CNES/Airbus, © 2018 DigitalGlobe): looking northeast from over the Lāchen Chú Valley towards the south face of the Khángchengyáo massif and the headwaters of the Lhāshar Chú – Jāchú River, including the proglacial lakes/ponds of Shāká Cho, Youlhá Khángtsá and Shärabū Cho; *TOP RIGHT:* a visual representation of local elders' spatial conception of the south face (Thánggū side) of the holy Khángchengyáo massif, with Shāká Cho, Youlhá Khángtsá and Shärabū Cho releasing *dütsi* or the nectar of immortality into the Lhāshar Chú – Jāchú River, and some of the other "108 blessed waters"; *LEFT:* a photograph (credit: Vaibhav Kaul, 2015) of the moraine-dammed Shāká Cho proglacial lake and the Shāká glacier flowing down Khángchengyáo to feed it

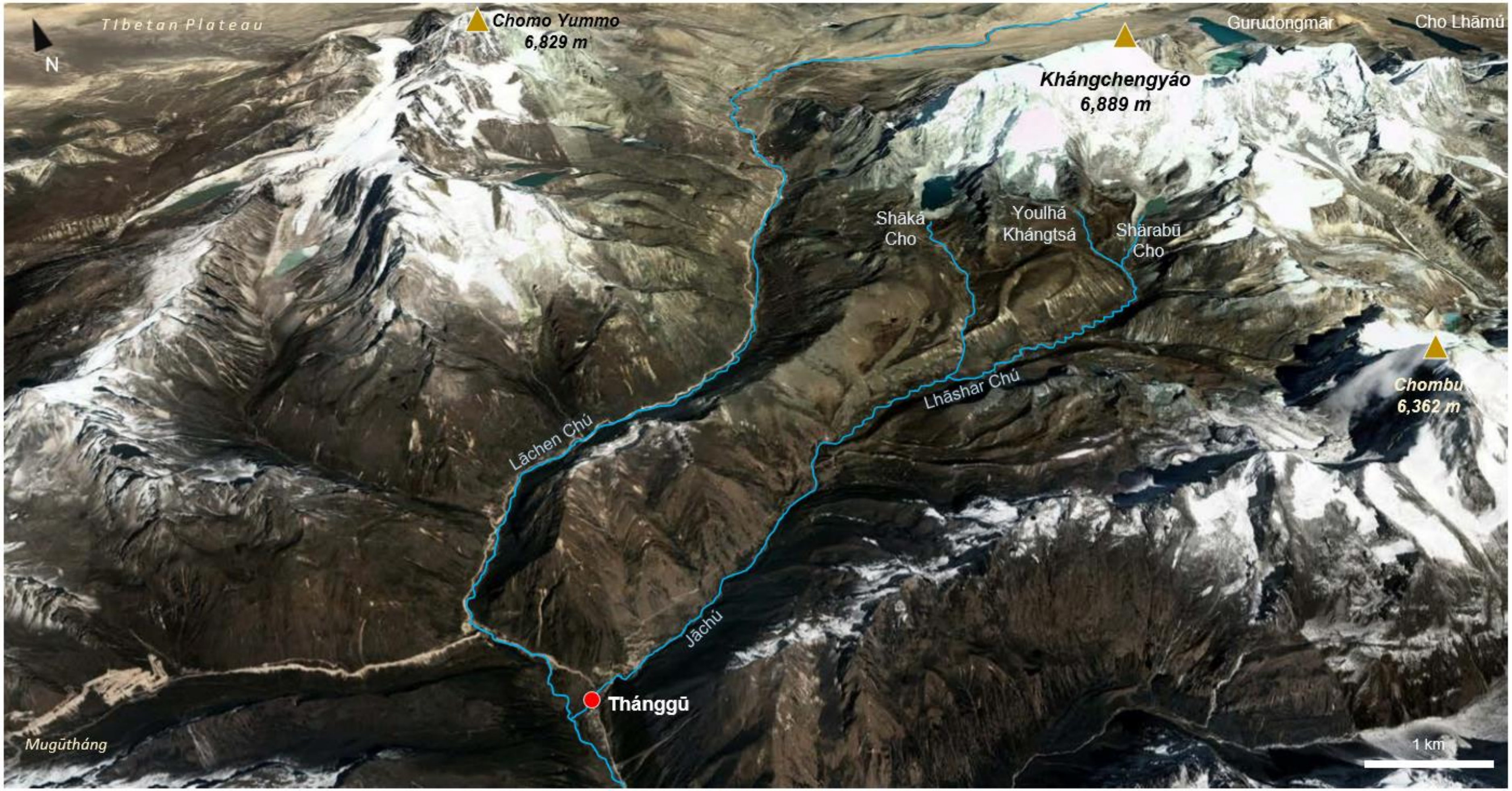


Fig. 5.4. Google Earth image (© 2018 CNES/Airbus, © 2018 DigitalGlobe): looking northeast from over the Lāchen Chú Valley towards the south face of the Khángchengyáo massif and the catchment of the Lhāshar Chú – Jāchú River, including its headwaters (Shāká Cho, Youlhá Khángtsá and Shārabū Cho) and its confluence with the Lāchen Chú River at Thánggū

Table 5.1. A comparison of Western scientific and local traditional understandings of the Shāká Cho glacial lake outburst flood "hazard" at Thánggū

<table>
<tr><th colspan="2">Description of the geomorphic hazard</th><th colspan="2">Qualitative present-day likelihood of occurrence</th><th colspan="2">Interacting climate change signals and their implications for the hazard</th><th colspan="2">Potential impact on the community at Thánggū</th></tr>
<tr><th>Western scientific interpretation</th><th>Local traditional interpretation</th><th>Western scientific view</th><th>Local view</th><th>Western scientific knowledge</th><th>Local knowledge</th><th>Physical</th><th>Metaphysical</th></tr>
<tr><td rowspan="3">Glacial lake outburst flood (GLOF) involving a catastrophic discharge from the Shāká Cho proglacial lake: Moraine dam failure triggered directly by high-intensity precipitation or/and indirectly via a precipitation-induced mass movement into the lake [FO: see Fig. 5.1; PAW: see Worni et al. 2013, Fig. 5.12, Table 5.2]</td><td rowspan="3">Release of the sacred Shāká Cho lake from the lap of the guardian mountain Khángchengyáo, and the descent of the lake's blessed waters in the form of dütsi, the death-conquering elixir: Opening of the moraine lap facilitated by precipitation in pursuance of karmic justice, as administered by the guardian mountain [CI/E]</td><td rowspan="3">Highly likely, particularly during the summer monsoon (June-early October), the wettest and warmest season [FO, PAW: see Fig. 5.12, Table 5.2]</td><td rowspan="3">Highly likely, particularly during the summer monsoon (June-early October), the wettest and warmest season: Opinions ranging from "possible" to "inevitable", often depending on perception of karmically determined need for calamity [CI]</td><td>Regional climate warming over the past half century (at 0.2-0.5°C per decade), with the steepest temperature increases (0.4-0.7°C per decade) observed at the highest elevations (>4,000 m) and in the winter season; regional climate projections indicating annual mean temperature increases of >4°C (and wintertime warming of >5°C) by the 2080s under the RCP 8.5, SRES A1B, SRES A2 scenarios [PAW: see Appendices 5A.1, 5A.2]

Implication: Amplification of the hazard through (i) glacier mass loss, heightened meltwater discharge, and proglacial lake expansion; (ii) moraine dam weakening due to ice core thawing; (iii) heightened risk of mass movements into the lake due to thermally induced destabilisation of the glacierised and periglacial slopes that descend into the Shāká Cho lake [FO, PAW]</td><td>Climate warming over the past half century, with the greatest temperature increases felt at the highest elevations [CI]

Implication: Amplification of the "hazard" through glacier shrinkage and increased meltwater discharge and glacier calving into the Shāká Cho lake, as regulated by karma through the guardian mountain Khángchengyáo [CI/E]</td><td rowspan="3">Several dozen casualties, complete or partial destruction of about two-thirds of the settlement: flooding of ~57 civilian buildings, at least half of the Army camp (including the helipad), large sections of the road (including a crucial bridge), and farmland; only the elevated monastery area (40-70 m higher than the riverbed) and the para-military (ITBP) camp on the slope below it (15-40 m higher than the riverbed) can be expected to remain safe [FO, PAW: see Figs. 5.12-5.14, Table 5.2]</td><td rowspan="3">An over-whelmingly powerful expression of geophysical energy, presenting a rare opportunity, upon survival or even immediately preceding death, to gain prajñā or deep emotional insight into nature and the human condition, which may eventually lead to a psychological state of complete invulnerability to every kind of physical hazard and suffering, representing liberation from the bondage of karma [CI/E]</td></tr>
<tr><td>Winter precipitation decline [PQDA] coupled with warming over the past three decades [PAW]; reduced amounts of precipitation presumably falling in even more reduced amounts as snow (owing to phase changes to sleet or liquid rain) under the influence of pronounced wintertime warming, which is the greatest at the highest elevations [see Section 5.1.2.1.2]

Implication: Amplification of the hazard through reduced glacier mass input, which leads to glacier shrinkage and proglacial lake expansion [PAW]</td><td>Sharp snowfall decline over several decades [CI]

Implication: Identical to that identified by Western science, except that the geological entities involved possess agency and intent, which they yield in pursuance of karmic justice [CI/E]</td></tr>
<tr><td>A likely increase in short-spell, high-intensity monsoon precipitation over the past three decades despite significant drying over the past century [PQDA: see Section 5.1.2.1.1]; regional climate projections indicating intensification of monsoon precipitation with sharp increases in extremes over the 21st century [PAW: see Appendix 4B.2]

Implication: Amplification of the hazard through (i) heightened risk of precipitation-triggered failures of periglacial and glacierised slopes leading to sudden water-displacing mass movements into the Shāká Cho lake; (ii) heightened risk of overspills directly due to excessive rainwater influxes into the lake; (iii) heightened risk of moraine dam failure, either as a consequence of (i) and/or (ii), or through the direct impact of rainfall [FO, PAW]</td><td>Increased monsoon precipitation intensity with a proliferation of short-spell, high-intensity rainfall events despite a sustained decline in total monsoon precipitation amount over several decades [CI]

Implication: Identical to that identified by Western science, except that the geological entities involved possess agency and intent, which they yield in pursuance of karmic justice [CI/E]</td></tr>
</table>

Data sources are provided in parentheses. PAW: published academic work, FO: field (geomorphological) observations, PQDA: primary quantitative data analysis, CI: community interviews, E: ethnography

The above local accounts of the Shākā Cho GLOF hazard are in agreement with my own field-based qualitative geomorphological appraisal of the hazard, which was informed by the Swiss scientists Worni et al.'s (2013) simulation modelling study as well as the wider literature on glacier-related hazards in mountain environments (see, for example, Richardson and Reynolds 2000, Clague and O'Connor 2015, Walder and Driedger 1995, Warburton and Fenn 1994, ICIMOD 2003, 2004, 2005). The available earth science-based knowledge of the situation at Shākā Cho is briefly reviewed below.

Located at an elevation of 5,000 m directly below the glacierised southwest face of Khángchengyáo (6,889 m) in India's Sikkim Himalaya, the moraine-dammed Shākā Cho proglacial lake gradually discharges meltwater by means of piping through the moraine into the Lhāshar Chú – Jāchú River, which joins the larger Lāchen Chú at Thánggū. The Lāchen Chú is one of the two main headstreams of the Tīstā, a major tributary of the mighty Brahmaputra River (see Figs. 5.6-5.11).

Worni et al. (2013) estimate the area, mean depth and volume of Shākā Cho at 0.575 km^2, 27 m, and 15.5 x 10^6 m^3 respectively. Using remote sensing and DEM-based analyses, they identify the associated outburst flood hazard as "highly critical", owing to the low width/height ratio (0.15) and unconsolidated structure of the lake-damming terminal moraine, the 1,000-metre-tall glacierised Khángchengyáo mountain face that rises very steeply from it (at angles exceeding 45° over large sections), and the considerable exposure of the Thánggū settlement to a flood originating from Shākā Cho. My field observations confirm and spatially elucidate the above risk factors, which are visually represented through annotated Google Earth satellite images, local-scale terrain maps, and ground photographs in Figs. 5.3-5.4, 5.7-5.11 and 5.13-5.14. Community members' insights into moraine dam stability are also fairly congruent with the above assessment.

Worni et al. also use a fluid dynamics and sediment transport model called BASEMENT to simulate a GLOF event involving a sudden mass movement into the lake, impulse wave generation and propagation across the lake, moraine dam overtopping and breaching, and, finally, lake drainage and flash flood propagation and impact at Thánggū and the smaller settlement of Yátháng further downstream (see Fig. 5.12, Table 5.2 for modelled outburst scenarios). Based on the magnitude of the GLOF-triggering mass impact, the model provides two outburst scenarios for Shākā Cho. The small and large impact scenarios generate, respectively, maximal discharges of 6,100 m^3s^{-1} and 6,950 m^3s^{-1}, with the flood wave impacting Thánggū about 50 minutes after the breaching of the dam and inundating and partially destroying about 100 buildings, farmland and sections of the road. Under both scenarios, the maximal velocity and maximal depth of the flow at Thánggū are estimated at 15 ms^{-1} and 12 m respectively. These quantitatively modelled scenarios fit fairly well with the community's qualitative, experiential knowledge of how a GLOF may play out.

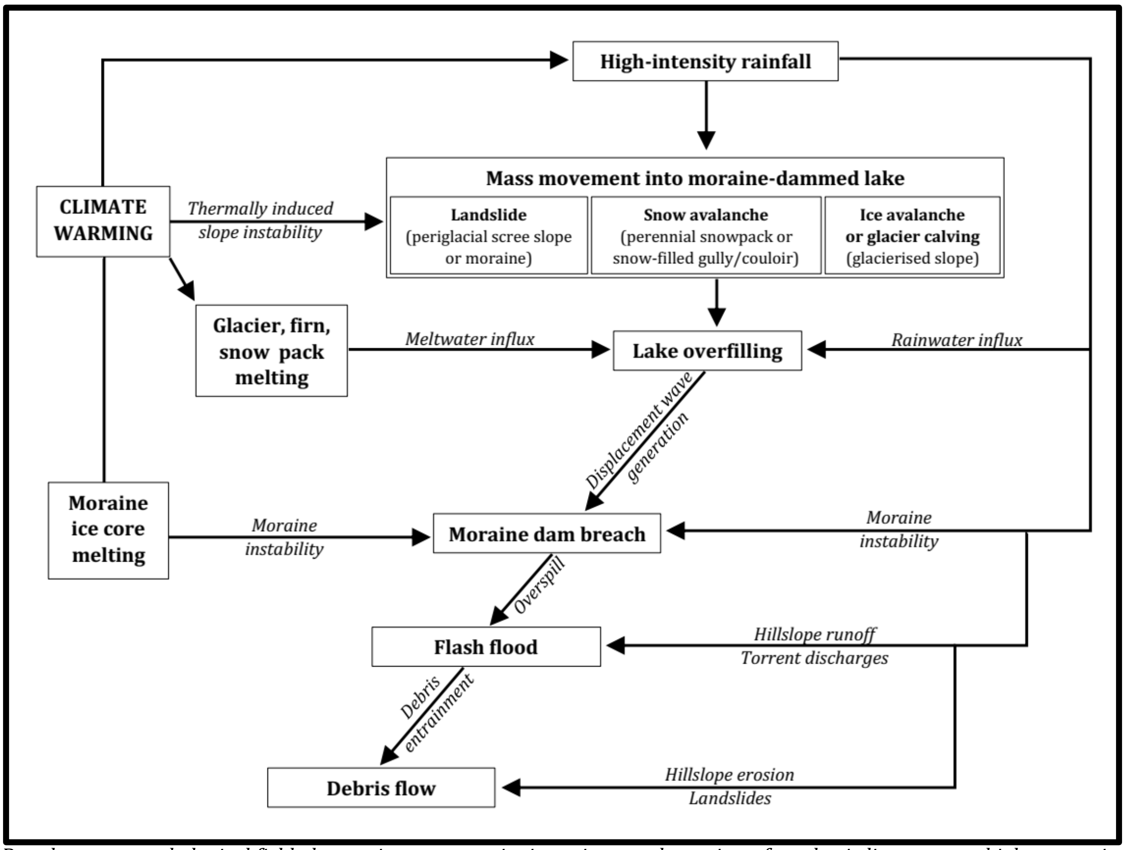
Using my own GPS-aided ground observations of active and inactive drainage channels and relief (including highly localised land cover effects) in the Thánggū settlement area, DEM-based village-scale topographic mapping (see Fig 5.13), and participatory viewings of the village landscape from vantage points with members of the community, buffers were qualitatively drawn along the Jāchú River at Thánggū to indicate approximate extents of flooding in case of flow depths of 5-6 m and 10-12 m (see Fig. 5.14). Based on this exercise, the likely human implications of a GLOF event with a flow depth of 10-12 m include several dozen casualties (more fatalities if the event occurs during the night) and complete or partial destruction of about two-thirds of the settlement (flooding of about 57 civilian buildings, at least half of the Army camp including the helipad, large sections of the road including a crucial bridge, and farmland).

The above estimate of damage is conservative in that it does not take into account potential contributions of water or sediment from any flash floods or debris flows that may concurrently originate in tributary streams, torrent channels and gullies, or a future landslide linked to the highly dense zigzag road construction on the slope flanking the right bank of the Jāchú River immediately upstream of its point of entry into the Thánggū settlement (see Fig. 5.14; see also Barnard et al. 2001, Hearn and Shakya 2017 for geomorphological commentaries on road construction and landslides). However, even in a relatively extreme situation, the elevated monastery area (40-70 m higher than the Jāchú riverbed) and the paramilitary (ITBP) camp on the slope immediately below it (15-40 m higher than the Jāchú riverbed) can be expected to remain safe (see Figs. 5.13, 5.14). These accessible minimal-risk locations off the right bank of the Jāchú, which members of the community also identify as safe, may be designated as refuge zones in future emergency evacuation plans.

Having compared and attempted to synthesise Western scientific and local physical understandings of landscape dynamics, I find that conceptualising the Shāká Cho situation simply as a GLOF hazard or even as a GLOF hazard operating in conjunction with other geological and climatic hazards downplays the role of the complex and often chaotic (and therefore difficult-to-quantitatively-model) *interactions* among these hazards in generating real-life experiences of extreme physical environments. On the other hand, considering interrelated phenomena such as climate warming, extreme precipitation, slope instability, glacier melting, flash flooding, etc. as components of a unified organism or functional whole arguably allows one to account for properties of the entire system that may be beyond the sum of the properties of its individual parts in that their very genesis may lie in the interactions among the various components. What is perhaps required, therefore, is to draw upon the ULC community's gestaltist (see Koffka 1935, pp. 17-22) or organismic view of the nexus of interacting hazards that is likely to be involved in a GLOF event originating from the Shāká Cho proglacial lake and impacting the community at Thánggū as a debris flow. This is what I intend to do through my integrative conceptual model of the climate-related geohazard complex facing the ULC community, which may also be applicable to other changing high-mountain landscapes with moraine-dammed lakes, at least within the Himalaya (see Fig. 5.5).

Fig. 5.5. Interactions among the multiple climate-related geohazards that are likely to be involved in a GLOF event originating from the Shākā Cho proglacial lake and impacting the ULC community at Thánggū

Note that the model is also applicable to the debris flow event faced by the Western Himalayan UM community in June 2013, which involved the catastrophic drainage of Chorābārī Tāl, a moraine-dammed lake located immediately upstream of the Kédārnāth settlement.



Based on geomorphological field observations, community interviews, and a review of academic literature on high-mountain glacier-related hazards

Climate warming acts the model's key driver. It enhances melting (and shrinkage) of glaciers and firn and snow packs, which in turn causes the volume of the moraine-dammed lake to increase with growing meltwater influxes over many years or decades. Warming also induces extreme precipitation events and thermally destabilises glacierised, snow-covered, periglacial scree and morainic slopes in the high-mountain environment, amplifying the hazard of sudden high-magnitude mass impacts on the moraine-dammed lake. A sudden mass influx induced by the above processes, combined with the hazard of direct extreme influxes of rainwater, may cause the lake to rapidly overfill and the resultant impulse to trigger the failure of the moraine dam. The moraine dam may have already been structurally weakened (and therefore made more susceptible to failure) by warming-induced ice core thawing over several decades. Also, the direct impact of high-intensity rainfall may have contributed to long-term moraine destabilisation as well as immediate failure. The outburst flood emanating from the breached moraine dam, augmented by hillslope runoff and any tributary flash floods, may entrain large volumes of debris (including destructive morainic and outwash boulders and gravel) before impacting riverside settlements. Additionally, intense rainfall may trigger severe erosion and a series of independent slides and flows, particularly along steep gullies, couloirs and torrent channels, which may eventually join and magnify the main debris flow as it travels down the trunk stream channel (see Section 2.1.1 for theoretical background). This situation was exemplified by the catastrophic debris flow event that the Western Himalayan UM community faced in June 2013, which is discussed in Section 5.3.

The above conceptual model of the Shākà Cho geohazard complex does incorporate the ULC community's holistic *physical* view of landscape dynamics into a largely Western scientific understanding of the environment. However, the incorporeal karmic dimension of local knowledge is so epistemically inconsonant with Western scientific environmental causality that an attempt at integrating the two seems futile. Despite their differences over the fundamental nature of causality, the two knowledge systems are united in implying that the moral responsibility for climate change-related hazards as well as hazards associated with other forms of anthropogenic environmental degradation (i.e. hazards of the 'Anthropocene') rests collectively on human beings as a consumptive force.

Fig. 5.6. Map showing the location of the Upper Lāchen Chú Basin research area in the Eastern Himalaya

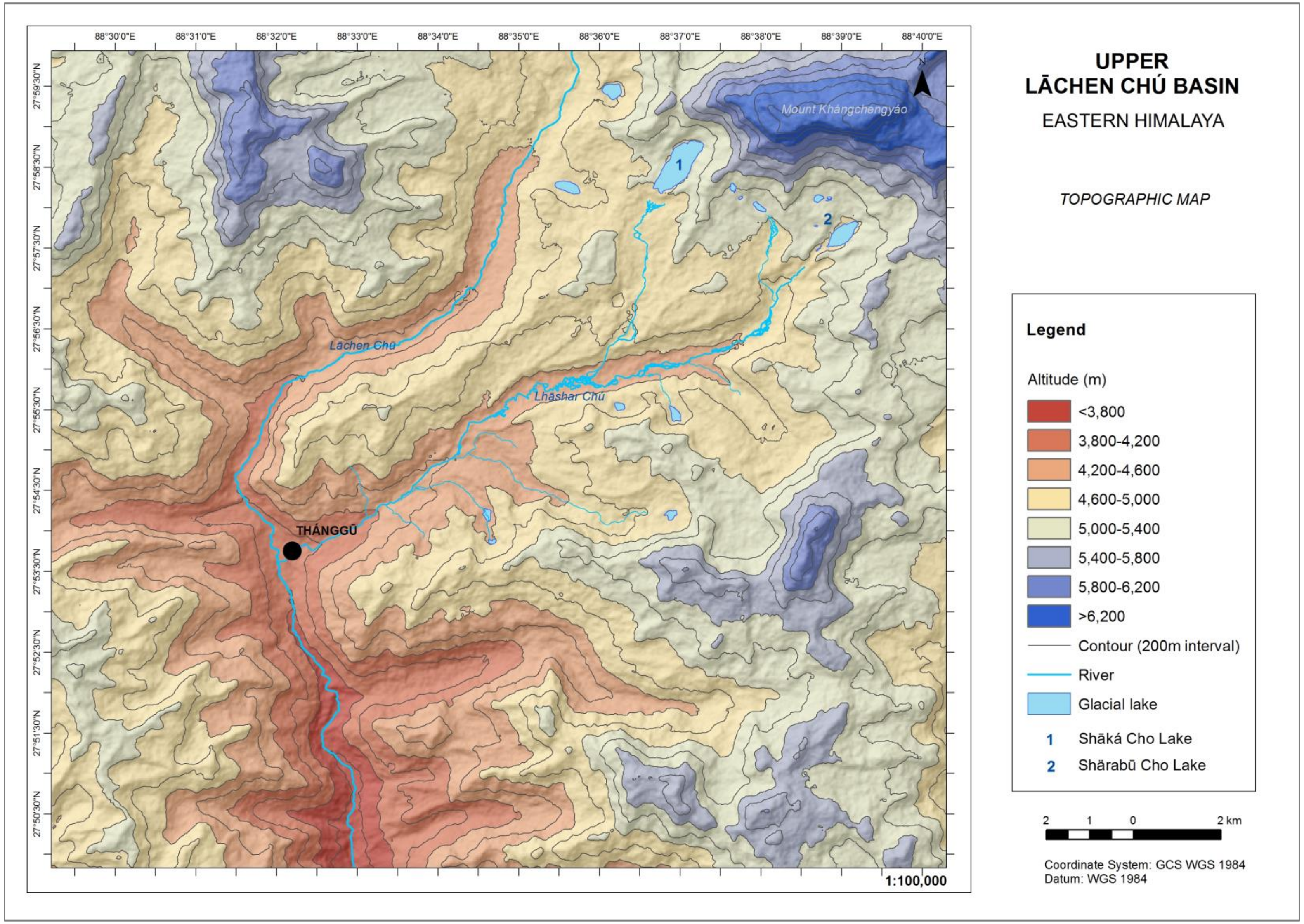


Fig. 5.7. Topographic overview map of the research area in the Upper Lāchen Chú Basin, North Sikkim

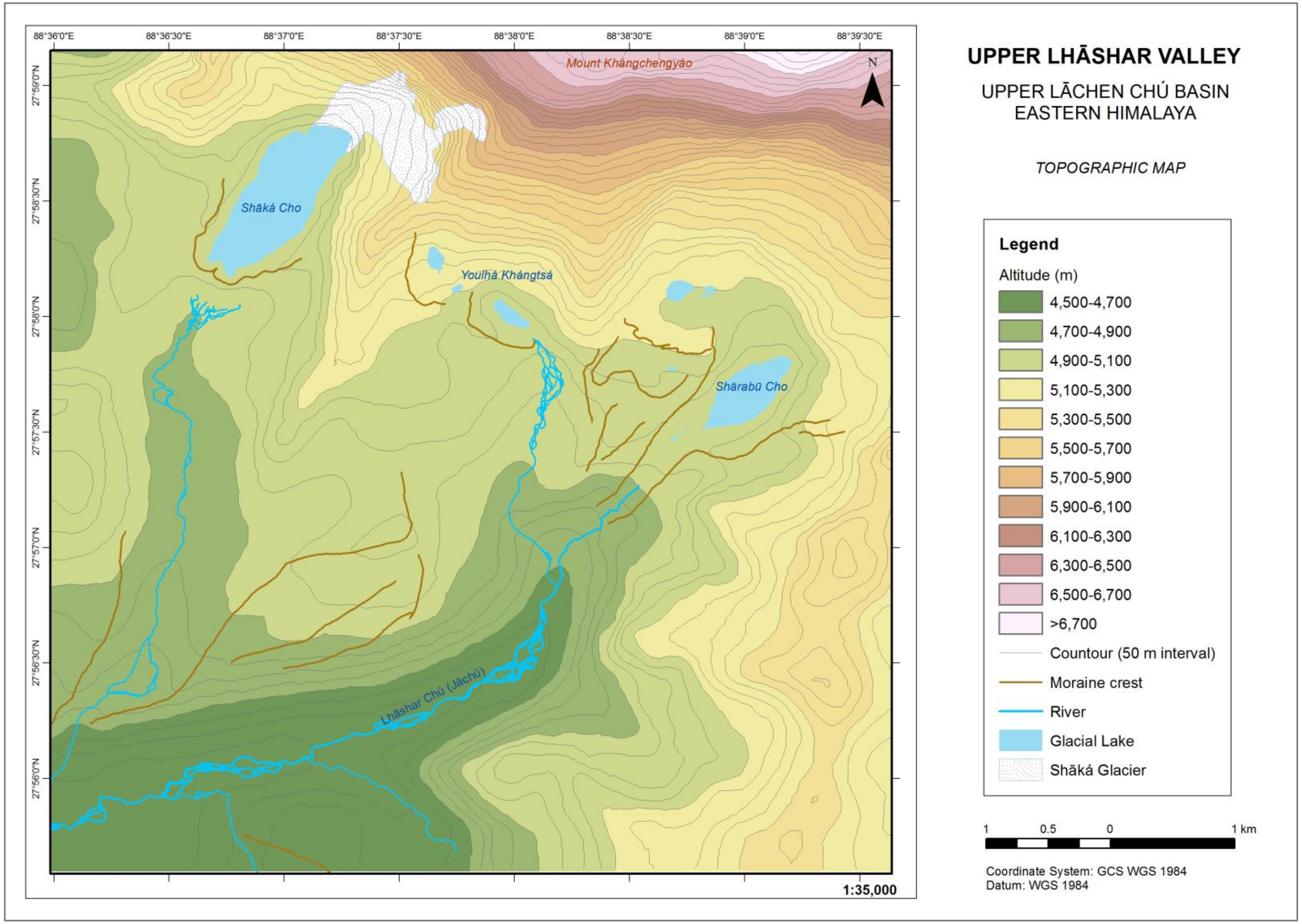


Fig. 5.8. Topographic map of the headwaters of the Lhāshar Chú – Jāchú River, North Sikkim

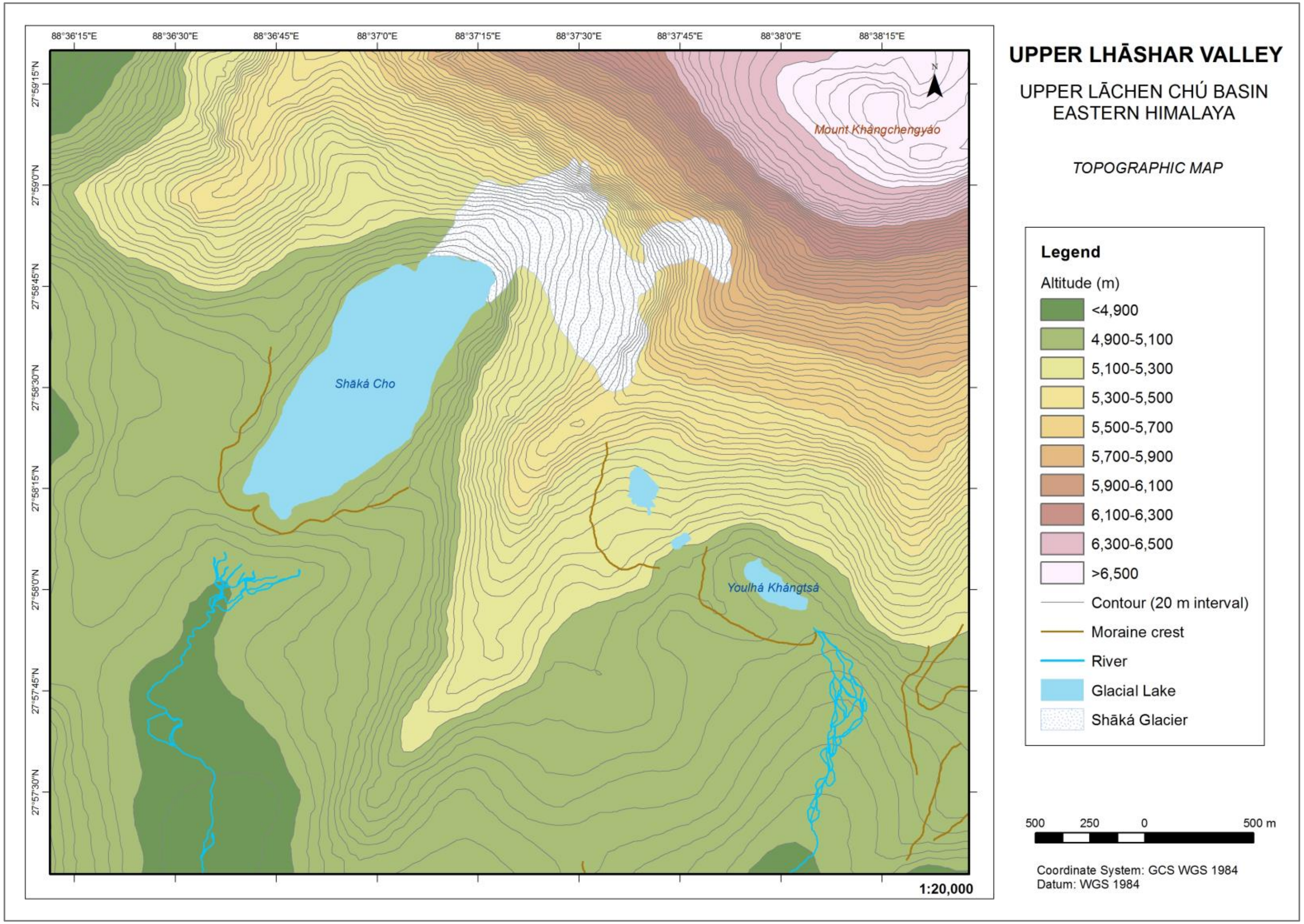


Fig. 5.9. Topographic map showing the setting of the Shākā Cho proglacial lake, North Sikkim

Fig. 5.10. Looking northeast towards the southwest face of the Khángchengyáo mountain and the upstream end of the Shākā Cho proglacial lake, which is dammed by a Little Ice Age terminal moraine and fed by the Shākā glacier, whose snout descends into its waters, regularly calving blocks of ice that create ripples across them (photo credit: Vaibhav Kaul, 2015): The glacierised and periglacial slopes flanking the lake on the northeast are potential sources of a GLOF-initiating mass impact on the lake, which currently discharges water only in the form of seepage through the base of the southwestern section of the moraine dam.

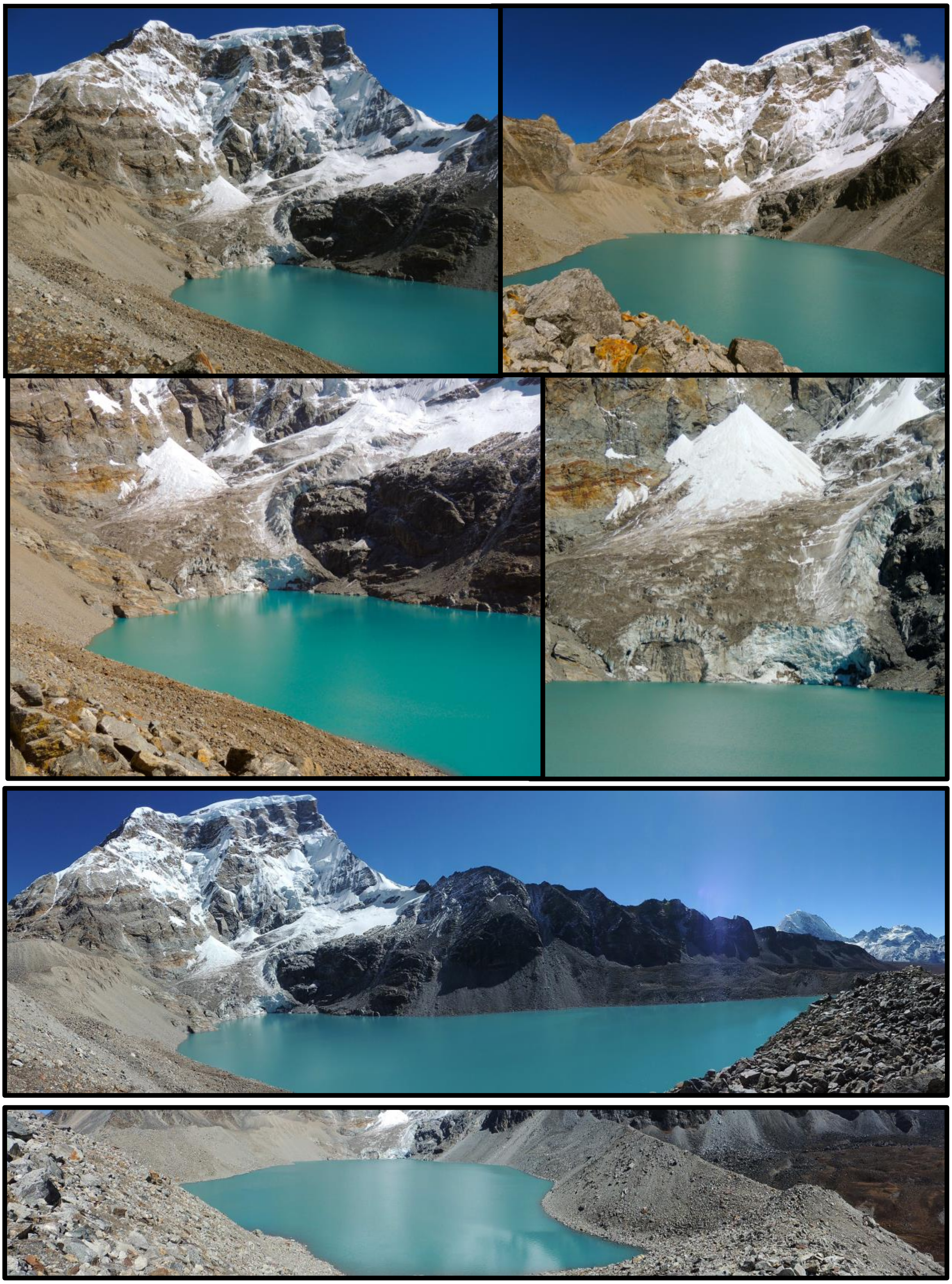
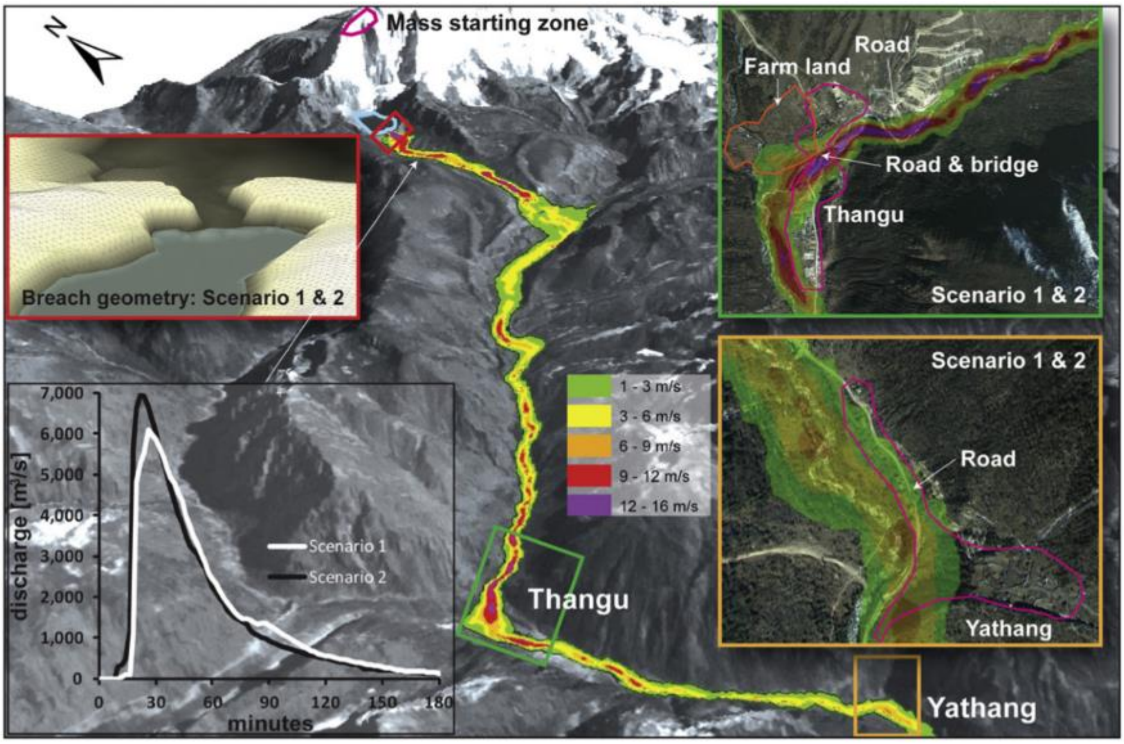


Fig. 5.11. *TOP (4):* Looking south towards the downstream end of the Shāká Cho proglacial lake and the Little Ice Age terminal moraine that impound its waters, with the lowest segment of the moraine dam crestline rising only about 7 metres above the 2015 post-monsoon dry season water level (indicating the potential for freeboards of <5 metres in the summer monsoon); *BOTTOM (1):* Looking southwest towards the southwestward-flowing Jāchú River, which carries the discharge from Shāká Cho through the village of Thánggū (photo credit: Vaibhav Kaul, 2014-2015)

Fig. 5.12. Modelled outburst scenarios for the Shāká Cho proglacial lake (Worni et al. 2013)

Flow velocities shown for large mass movement impact (Scenario 2 in Table 5.2); breach geometry (see also Fig. 5.11 moraine photographs) and lake outburst hydrographs (GLOF discharge over the 180 minutes following moraine breach) shown for both scenarios – small impact (1) and large impact (2); water assumed to be released into lake from marked mass movement (avalanche) starting zone



Reproduced with permission from Worni et al. (2013)

Table 5.2. Modelled outburst scenarios for the Shāká Cho proglacial lake (Worni et al. 2013)

Parameter	Impact Scenario	
	1 (Small)	2 (Large)
Momentum flux* (N.s)	2.55×10^{10}	4.07×10^{10}
Impact volume^ (m^3)	2,300,000	2,800,000
Maximal breach depth (m)	43	45
Maximal breach width (m)	140	180
Maximal discharge (m^3s^{-1})	6,100	6,950
Fall in lake water level (m)	32	
Volume of water released in 180 min (m^3)	16×10^6	
Time lag between dam breach and flood wave impact at Thánggū (minutes)	50	
Maximum flow velocity at Thánggū (ms^{-1})	15	
Maximum flow depth at Thánggū (m)	12	
Probable damage at Thánggū	Inundation and partial destruction of about 100 buildings, three bridges, sections of the road, and farmland	

*Momentum flux (trigger pulse that induces wave generation, resulting in dam breach) is calculated as $\int \rho \bullet Q \bullet v \bullet dt$, where ρ = density of water, Q = water discharge into lake, v = velocity at lake impact, dt = time step of constant water flow.

^Owing to differences in immersion processes of liquids and solids, the modelled impact volumes (of water) are not representative of impact volumes (of rock, debris, or ice) that would actually occur in a trigger event involving mass movement.

Source: Based on Worni et al. (2013)

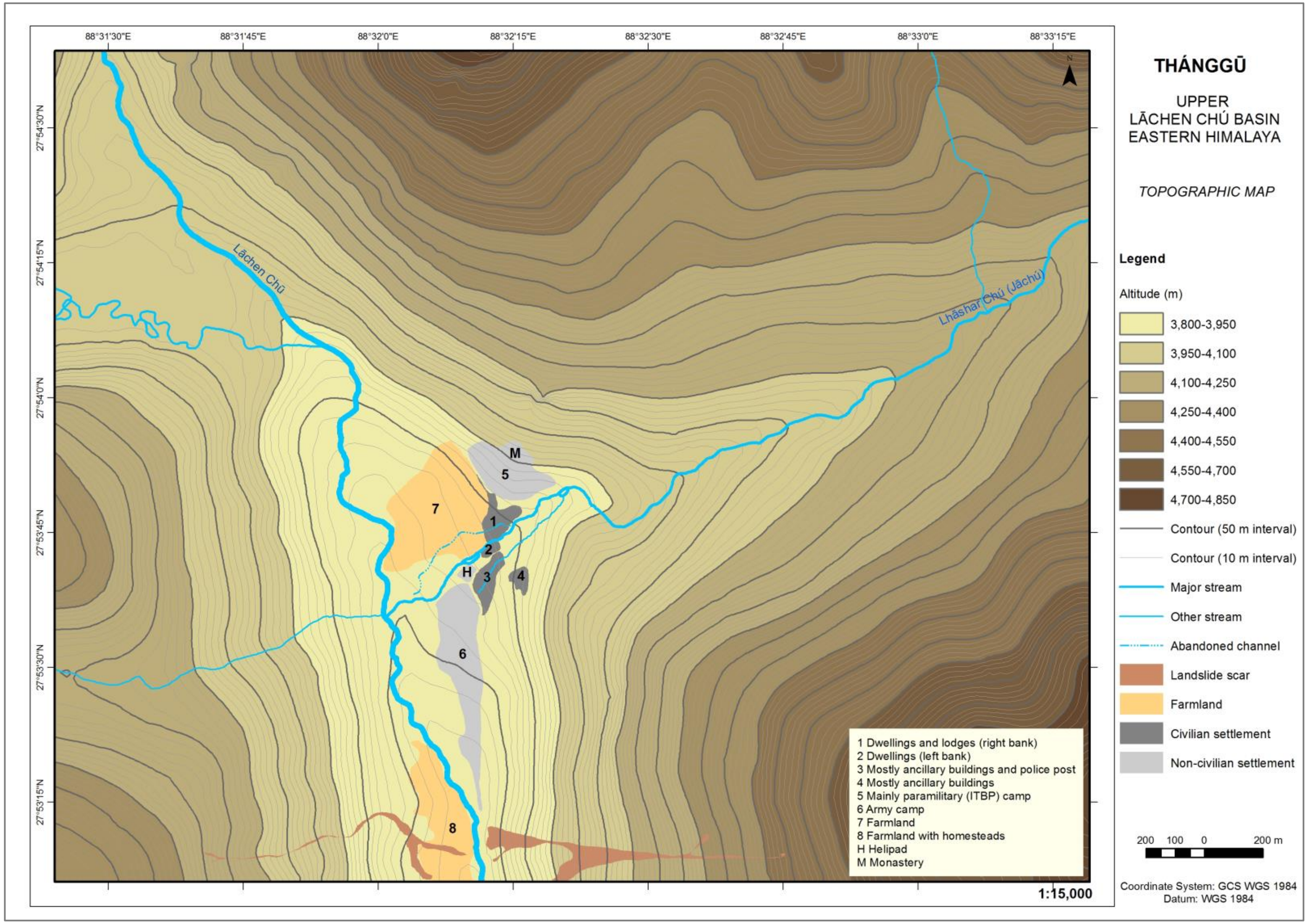


Fig 5.13. Topographic map showing the spatial configuration of the settlement at Thánggū in relation to the GLOF-susceptible Jāchú River

Fig. 5.14. Approximate, qualitatively assessed extents of flooding at Thánggū in the event of a GLOF (along the Jāchú River) with a flow depth of *5-6 metres* (shown in *rust*) and one with a flow depth of *10-12 metres* (shown in *yellow*)

Based on GPS-aided ground observations of active and inactive drainage channels and relief (including highly localised land cover effects) in the settlement area, DEM-based village-scale topographic mapping (Fig. 5.13), simulation modelling-derived GLOF impact scenarios by Worni et al. 2013 (Fig. 5.12), and participatory viewings of the village landscape from vantage points with members of the community

Base image: Google Earth (© 2018 DigitalGlobe)

Fig. 5.15. The shallow bed of the GLOF-susceptible Jāchú River immediately upstream of the high-risk settlement at Thánggū (photo credit: Vaibhav Kaul, 2015)

Fig. 5.16. Looking north/northeast from the main motor bridge at Thánggū towards the right bank of the GLOF-susceptible Jāchú River, with several properties (mostly lodges) located less than 10 metres above the river bed; the Thánggū monastery is seen at a safe elevated location in the background, above a slope over which the ITBP (paramilitary) camp is spread (photo credit: Vaibhav Kaul, 2015).

Fig 5.17. The GLOF-susceptible Jāchú River flows through Thánggū, with high-risk properties (located less than 10 metres above the river bed) along both banks; the Army helipad and camp are seen on the left bank of the river at the far end of the bottom image (photo credit: Vaibhav Kaul, 2015).

5.3. Insights from the Upper Mandākinī Valley

At least partly as a result of past disasters, the UM community's knowledge of the physical environment is both wide and spatially detailed. Interviewees identify 12 precipitation-related geohazards in the valley, which they also regard as having contributed to the 2013 disaster; the ensuing inductively devised genetic typology of hazards reflects a sophisticated and fairly comprehensive local understanding of high-mountain hydro-geomorphic processes:

(i) *Malbé vālī bārh* (lit. 'debris-rich flood'): Viscous flash floods and debris flows that originate in the main river or other established stream channels *(nadī kī bārh)* or those that run along steep mountain torrent channels (*nālé kī bārh*) (reported by 100% of 30 interviews)

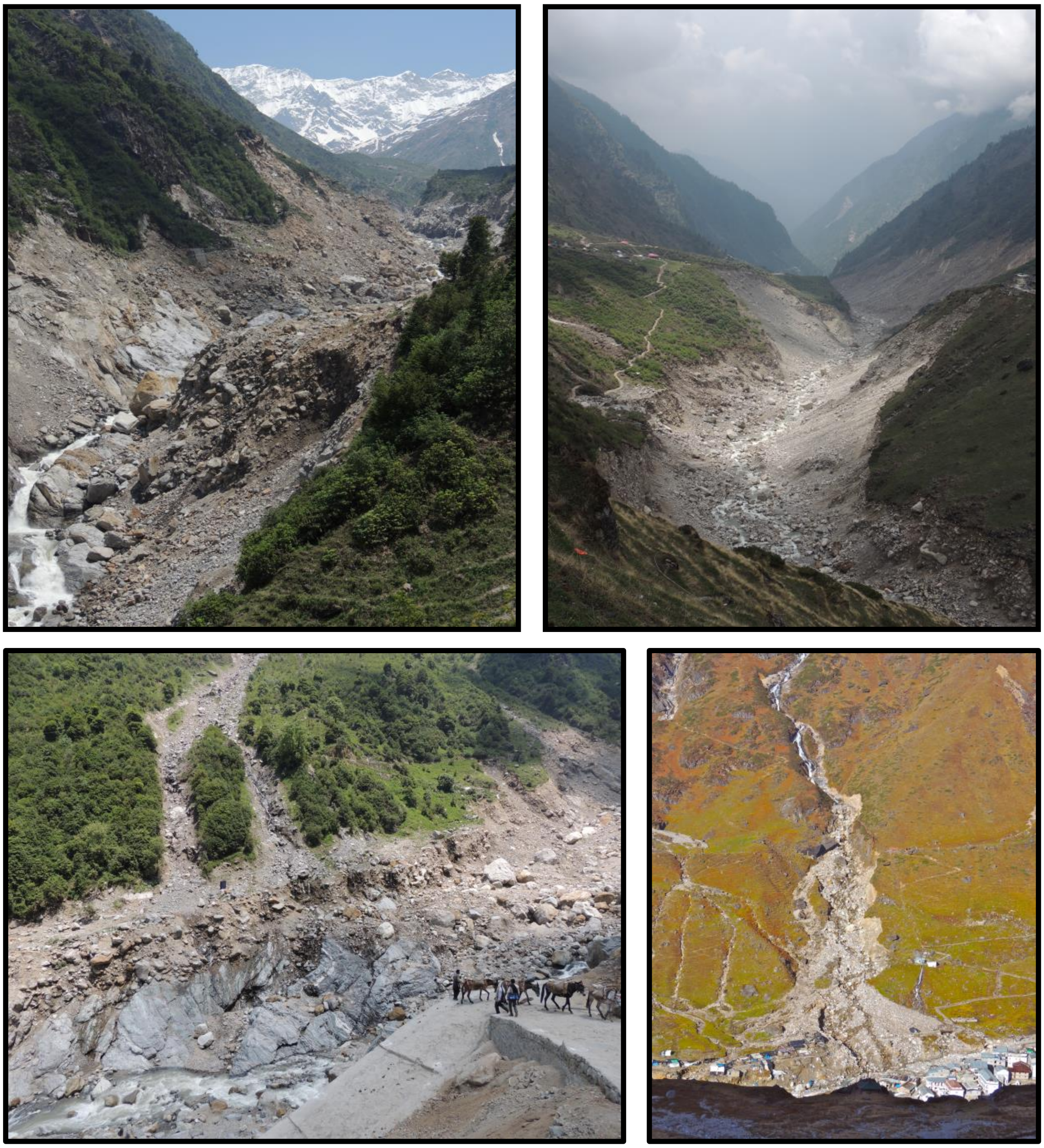


Fig. 5.18. Geomorphic impressions of *malbé vālī bārh* events that occurred in the Upper Mandākinī Valley during the June 2013 disaster; *TOP LEFT, TOP RIGHT: nadī kī bārh; BOTTOM LEFT: nadī kī bārh* and *nālé kī bārh* scars coming together at Rāmbāra, a settlement that was obliterated during the disaster; *BOTTOM RIGHT: nālé kī bārh* (photo credit: Vaibhav Kaul, 2013, 2014, 2016)

(ii) *Pahār girnā* or *pahār tūtnā* (lit. 'collapse of the mountain'; alternatively, *bhūskhalan or sliding*): Extensive earth slides on mountain slopes, particularly those that are not associated with riverine erosion (reported by 97%)

Fig. 5.19. Geomorphic impressions of *pahār girnā* events that occurred in the Upper Mandākinī Valley during the June 2013 disaster (photo credit: Vaibhav Kaul, 2013, 2014)

(iii) *Tālāb phatnā* or *Jhīl phatnā*: Lake outburst (reported by 93%)

Fig. 5.20. The ruptured moraine that had dammed the seasonal Chorābārī Tāl lake for at least a century until a catastrophic *tālāb phatnā* event was caused by a precipitation-triggered mass movement during the June 2013 disaster (photo credit: Vaibhav Kaul, 2014)

(iv) *Malbā ānā* (lit. 'coming of debris'): Debris flows, particularly those whose downslope movement is not associated with established stream channels or those that originate in shallow, steep mountain torrent channels (reported by 80%)

Fig. 5.21. Geomorphic impressions of a June 2013 disaster *malbā ānā* event, viewed from the base and crest of the Last Glacial lateral moraine located above the terrace along the left bank of the Mandākinī River at Kédārnāth (photo: Vaibhav Kaul, 2014, 2016): During the event, viscous debris flows generated by mountain torrent flash floods on the mountainside behind and above the moraine tore through the moraine crest, causing a boulder- and gravel-rich debris flow to make its way down the moraine onto the terrace, which, despite the conspicuous imprint of the 2013 event, has been developed since a year after the disaster as the site of a key helipad and a new and expanding seasonal settlement (comprising a tent colony and a tin-roofed cabin complex) capable of accommodating a few thousand pilgrims.

(v) *Pahār behnā* (lit. 'mountain being washed away'): Extensive fluvial erosion coupled with failures of slopes flanking the main river, with landslide scars often rising a few hundred feet from the riverbed (reported by 63%)

Fig. 5.22. Geomorphic impressions of *pahār behnā* events that occurred between Lenchaulī and Garurchattī in the Upper Mandākinī Valley during the June 2013 disaster (photo credit: Vaibhav Kaul 2013, 2016)

(vi) *Dhartī ākāsh ék honā* or *zamīn āsmān ék honā* (theatrical; lit. 'earth and sky becoming one'; alternatively, *Himalayan tsunami*): Multiple, interacting high-magnitude fluvial and slope-related (and potentially also glacier-related) hazards triggered by intense rain (reported by 60%)

Fig. 5.23. Panoramic views of the Chorābārī glaciers and the Kédārnāth settlement amidst geomorphic impressions of the combined action of a lake outburst, flash floods and debris flows at the head of the Mandākinī valley and along tributary torrent channels during the June 2013 disaster (photo credit: Vaibhav Kaul, 2013)

(vii) *Pahār katnā* (lit. 'mountain being cut'): Extensive, incisive riverbank erosion (reported by 57%)

Fig. 5.24. Geomorphic impressions of a June 2013 disaster *pahār katnā* event at Kédārnāth that involved the catastrophic and extensive incision and activation of a minor abandoned stream channel by morainic debris flows carried by the Sarasvatī River (the eastern headstream of the Mandakinī River, fed by the Chorabārī East Glacier), whose confluence with the main Mandakinī channel consequently shifted from a location immediately upstream of the Kédārnāth settlement to a location immediately downstream of it (photo credit: Vaibhav Kaul, 2013; see Fig. 5.37 for a comparison of the Sarasvatī River's pre-disaster course, which was maintained by a concrete dyke, with its current, post-*pahār katnā* active channel)

(viii) *[Pathrīlī] daldal ānā* (lit. 'coming of [stony] quicksand'): Cloggy mudflows, particularly those that result from flash floods breaking out of river channels to entrain morainic/outwash sediments, typically including large amounts of fine glacial flour as well as boulders (57%);

Fig. 5.25. Geomorphic impressions of a June 2013 disaster *pathrīlī daldal ānā* event along the shop-lined path leading to the Kédārnāth Temple (photo credit: Vaibhav Kaul, 2013)

(ix) *Glacier ānā* (lit. 'coming of the glacier'): Wintertime snow avalanches (*himadhāva* in Hindi) that run over the surfaces of perennial, glacier-like firn packs that have evolved from long-term seasonal deposition of snow along mountain torrent channels (reported by 53%)

Fig 5.26. A section of the newly constructed post-disaster pilgrims' trail to Kédārnāth that has been carved through a perennial firn pack occupying a mountain torrent channel over which winter avalanches regularly slide (photo credit: Vaibhav Kaul, 2016)

(x) *Patthar girnā:* Rockslides (reported by 47%)

Fig. 5.27. Geomorphic impressions of *patthar girnā* landslides that occurred during the June 2013 disaster between Sonprayāg and Gaurīkund in the Upper Mandākinī Valley (photo credit: Vaibhav Kaul, 2013)

(xi) *Glacier kā malbā ānā* (lit. 'coming of the glacier's debris'): Morainic debris flows with entrained outwash boulders and gravel (reported by 47%)

Fig. 5.28. Geomorphic impressions of the boulder-rich morainic debris flows that ravaged Kédārnāth during the June 2013 disaster (photo credit: Vaibhav Kaul, 2013, 2014); TOP LEFT: The twin Chorābārī glaciers, whose erosive action over centuries generated the debris that was entrained by the June 2013 flood; BOTTOM: The millennium-old Kédārnāth Temple (A) and the 10-metre-wide boulder (B) that stood behind it during the flood, shielding it to a considerable extent

(xii) *Glacier phatnā*: glacier outburst involving a sudden discharge of meltwater from a mass of ice; *glacier tūtkar girnā* (lit. 'glacier breaking off'): calving-like collapse of crumbling ice blocks from crevassed sections of a glacier, often capable of generating a sudden discharge of meltwater upon coming into contact with intense rain (both reported by 33%).

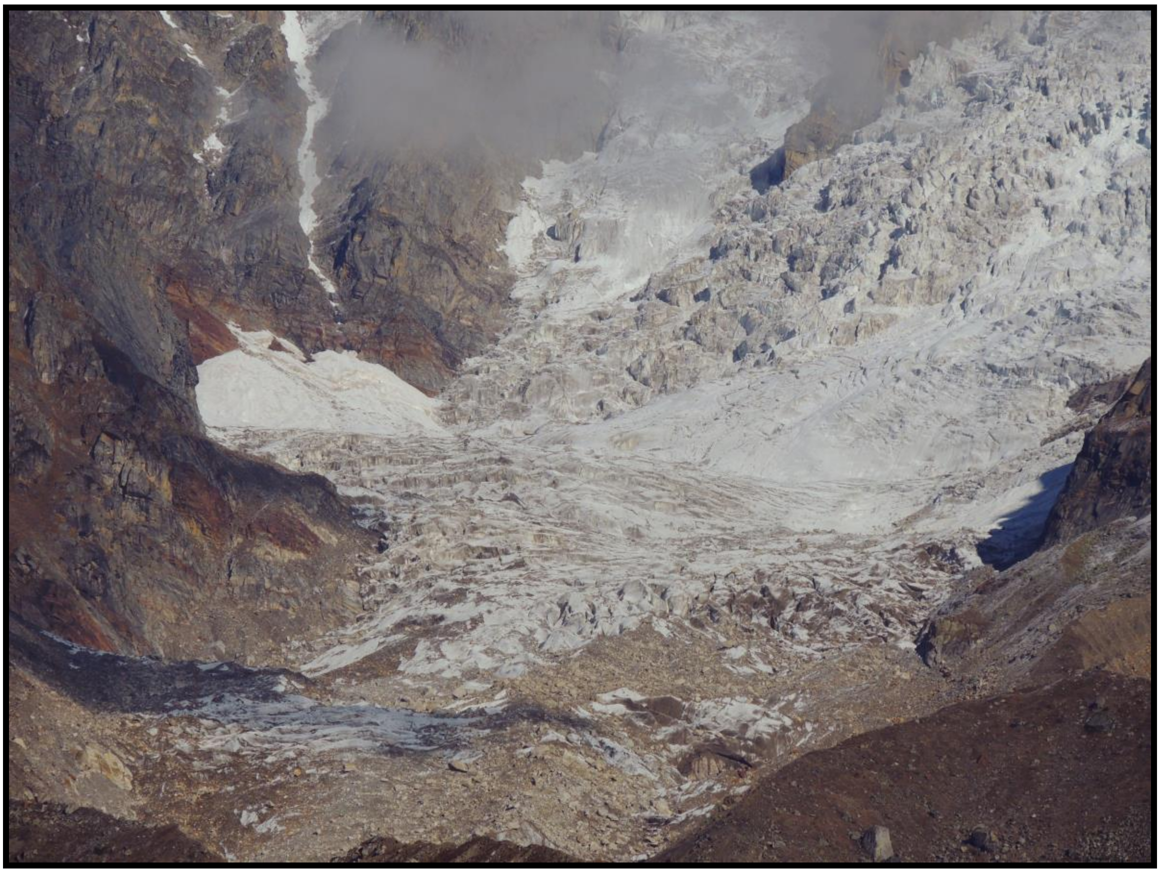


Fig. 5.29. An icefall section of the Chorābārī Glacier (with crevasses, moulins and séracs) located upstream of the lateral moraine-dammed Chorābārī Tāl lake that drained catastrophically during the June 2013 disaster (photo credit: Vaibhav Kaul, 2013)

Since the above typology of hazards reflects the community's long-term lived experiences and operates at a spatial scale useful for mitigative and adaptive interventions, it is arguably no less noteworthy than any geotechnically derived "scientific" empirical expositions of the kinds of hydro-geomorphic hazards present in the UM valley and similar terrains across the wider cultural landscape (cf. Hungr et al. 2001; see also Table 2.1). The Hindostānī-language terms and concepts used by the UM community are likely to be widely understood in similar high-altitude environmental settings across the Western Himalayan region, including northern Pakistan and the northern Indian states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand. Being highly context-specific and sensitive to regional and local geographical peculiarities, this kind of experiential knowledge could provide a template for adapting externally designed and epistemically "foreign" geophysical risk assessments to ground conditions.

The UM community's nuanced *physical* understanding of landscape dynamics in the UM valley covers nearly all of the individual geohazards and associated processes that have been identified in published earth science-based reconstructions of the June 2013 disaster at Kédārnāth (see Petley 2013, Dobhal et al. 2013, Durga Rao et al. 2014, Das et al. 2015, Martha et al. 2015, Allen et al. 2016, Bhambri et al. 2016, Mehta et al. 2017) as well as in my own field-based geomorphological observations (see Figs. 5.30-5.39). A spatially referenced earth science-based appraisal of the geophysical events that came together to generate the Kédārnāth disaster is presented below (see Fig. 5.5 for a conceptual model of the hazard complex). It is intended to give a spatialised sense of local geohazards and serve as a prelude to a geographically rooted exegisis of the community's complex *metaphysical* interpretations of the same hazards and the landscape in which they operate.

The topographic setting in which the June 2013 Kédārnāth disaster took place is depicted at multiple spatial scales in Figs. 5.30-5.34. The settlement of Kédārnāth is located at an elevation of about 3,550 m on the outwash plain of the twin Chorābārī Glaciers at the head of the valley of the Mandākinī River, a headstream of the Ganges in the Garhwāl Himalaya, Uttarakhand state, India. The two headstreams of the Mandākinī – the northwesterly Mandākinī stream, fed by the Chorābārī (Main) Glacier, and the northeasterly Sarasvatī stream, fed by the Chorābārī East (Companion) Glacier – come together at the Kédārnāth settlement (see Fig. 5.33).

Dobhal et al. (2013) report that 325 mm rainfall was recorded near the snout of the Chorābārī Main Glacier and the moraine-dammed Chorābārī Tāl lake over the 24-hour period between 17:00 on 15 June and 17:00 on 16 June 2013. This amounts to 24% of the 2007-2012 mean of total seasonal June-September precipitation (1,343 mm) for the same location; in other words, about a quarter of four monsoon months' worth of rain fell in the 24 hours preceding the debris flow disaster at Kédārnāth. At Dehradun in the foothills, 17 and 16 June 2013 were the two wettest June days on record; at 370.2 mm and 219.9 mm, respectively, the rainfall values for the two days were as extreme as 424% and 252% of the 99th percentile of daily precipitation in June, observed over 1901-2014. Likewise, the total rainfall received at Dehradun from 15 until 17 June 2013 was the highest value on record for any three consecutive days in June; at 643.6 mm, it was 306% of the mean monthly June precipitation for the period 1901-2014 (see Section 4.1.2.1.1).

Two distinct rainfall-triggered debris flow events were involved in the disaster. The first flood impacted the Kédārnāth settlement from about 17:00 until about 21:30 on the evening of 16 June 2013. It involved the Sarasvatī stream, the eastern headstream of the Mandākinī, which is fed by the Chorābārī East (Companion) Glacier. Severely heightened erosive influxes of rainfall runoff and snowmelt into steep gullies, couloirs, and ephemerally or seasonally active torrent channels in the catchment of the Sarasvatī stream (see Fig. 5.36: particularly around A1, where a significant landslide seems to have been initiated, but also A2 and A3; see also Martha et al. 2015), possibly supplemented by rapid meltwater discharges from any small englacial, subglacial and/or supraglacial pools associated with the Chorābārī East Glacier, caused the Sarasvatī stream to overflow its banks and entrain large volumes of morainic and outwash sediments, including highly deleterious boulders and gravel.

The debris flow tore through and obliterated an artificial concrete dyke that had been in use to divert/train the Sarasvatī westwards so that it would join the main (western) headstream of the Mandākinī upstream of the Kédārnāth settlement. The flow then reactivated and very extensively incised the old disused channel that marked the eastern margin of the Kédārnāth settlement, thereby shifting the confluence of the Sarasvatī and main Mandākinī headstream to a location immediately downstream of the Kédārnāth settlement (see details in Fig. 5.37, see Fig 5.36: A4, A5, A6; see also Martha et al. 2015). This affected the entire Kédārnāth settlement and completely destroyed about a quarter of the >250 buildings there, particularly those located upstream (north) of the millennium-old temple and in the eastern half of the settlement, along the newly reactivated Sarasvatī channel. As the flood travelled downstream along the Mandākinī, it made the river swell to 30-50 m above the river bed in certain sections of the valley (Mehta et al. 2017), sweeping away and obliterating the entire right-bank settlement of Rāmbāra (~90 buildings: Bhambri et al. 2016) and causing extensive destruction at Gaurīkund, Sonprayāg and other inhabited locations further downstream.

The second and more intense of the two floods occurred between 5:45 and 6:15 on the morning of 17 June 2013. It involved the catastrophic emptying of Chorābārī Tāl, a small lake fed mainly by rainfall and snowmelt runoff and dammed between a steep mountain front and the curved terminal section of the western lateral moraine of the Chorābārī Glacier (Fig 5.36: B3, Fig. 5.20). The lake outburst event was initiated by the sudden failure of the 40-metre-tall southern section of the moraine dam (Fig. 5.36: B4), which is supposed to have been triggered by a rapid rainfall-triggered mass influx into the already overfilled lake (Fig. 5.36: B1, B2). The mass influx would have comprised debris (from a rainfall-triggered landslide on the lateral moraine that marked the eastern boundary of the lake and from erosion upstream of the lake: Allen et al. 2016) and/or snow and snowmelt (from a rainfall-triggered avalanche over the steep mountainside that marked the western boundary of the lake: Mehta et al. 2017, Bhambri et al. 2016, Dobhal et al. 2013).

Mehta et al. (2017) estimate that the moraine-dammed Chorābārī Tāl had an area of 5.7 x 10^4 m^2 and a mean depth of 19 m immediately prior to the disaster. They also estimate and that following the moraine breach, the lake released 6.1 x 10^5 (± 1.0 x 10^5) m^3 of water, draining completely within 15 minutes or less at a mean discharge rate of about 1429 m^3s^{-1}, and excavating and entraining about 2.1 x 10^6 m^3 of morainic debris as it flowed down steeply (at channel gradients of 10°-25°: Allen et al. 2016, field observations; see Fig. 5.36: B5, B6, B7, B8, B9, B10) to arrive on the relatively flat outwash plain (slope <5°) occupied by the Kédārnāth settlement, where about 3.9 x 10^6 m^3 of debris was found to have been catastrophically deposited (Fig. 5.36: B11).

Extensive damage was also caused by highly erosive debris flows that concurrently came down steep couloirs, gullies and torrent channels (such as D1-D4, C1-C3 in Fig. 5.36) before joining and significantly magnifying the main Mandākinī flood in the trunk valley. Off the left (eastern) bank of the Mandākinī immediately downstream of the Kédārnāth settlement, the extensive Last Glacial moraine ridge that runs along the mountain front initially held behind its crest much of the rapid sediment and water discharge from the steep gullies above (Fig. 5.36: C4). However, the accumulated material eventually tore through the moraine crest, causing boulder- and gravel-rich debris flows to make their way down the moraine onto the riverside terrace (Fig. 5.36: C6, C7, C8), which, despite the conspicuous imprint of the 2013 event, has been developed since a year after the disaster as the site of a key helipad and a new and expanding seasonal settlement (comprising a tent colony and a tin-roofed cabin complex) capable of accommodating a few thousand pilgrims (Fig. 5.36: C9, Fig. 5.21).

Bhambri et al. (2016) compare pre- and post-disaster high-resolution satellite imagery to identify geomorphic imprints of as many as 137 debris flow events (mainly along steep tributary channels that drain into the Mandākinī River) between Kédārnāth and Sonprayāg (see Fig. 5.31) in the Upper Mandākinī Valley. They find the debris flow runout area in this section of the valley to have increased 575% (±41%) and the area affected directly by destructive erosional and depositional activity along the main Mandākinī River channel to have increased 407% (±29%) between the pre- and post-disaster images. Figs. 5.32, 5.34, 5.35 and 5.37 illustrate some of the terrain changes that were caused by the June 2013 events around the Kédārnāth settlement.

Of the 259 structures (mostly pilgrims' lodges) in the Kédārnāth settlement, 138 (53%) were completely wiped out and 56 (22%) were partially destroyed as a result of the two major debris flow events (Das et al. 2015). Although located in the uppermost and therefore the most exposed and thoroughly devastated part of the Kédārnāth settlement, the millennium-old temple of Lord Shiva remained largely undamaged, presumably for three reasons. Firstly, the temple has a very robust structure with thick local granitic/gneissic slabs. Secondly, the floor plan of the building is elongated in the direction parallel (rather than perpendicular) to that of the valley and the debris flow, which minimised the surface area exposed to the force of the flow. Thirdly, an exceptionally large boulder, about 10 m in width and about 80 m^3 in volume, stood directly behind the temple as a shield, splitting the debris flow into two strands, both of which narrowly missed the temple and destroyed adjacent buildings (see Fig. 5.28). Almost all of the few other buildings that saw little damage from the debris flows also had thick stone walls (e.g. the century-old Nepal Bhawan), had their long axes aligned parallel to the debris flows, or were part of dense clusters of buildings and were sheltered by the more exposed buildings within those clusters.

Using my own GPS-aided ground observations of active and inactive drainage channels and relief in and around the Kédārnāth settlement area, DEM-based local-scale topographic mapping (see Fig 5.32-5.34), and participatory viewings of the landscape from vantage points with members of the community who witnessed the June 2013 disaster event, approximate spatial extents of damage were qualitatively estimated for two hypothetical future events triggered by extreme rainfall: (i) a 3-4-metre-deep debris flow associated with a riverine flash flood (*nadī kī bārh*) along the Sarasvatī channel, similar to the initial 16th June component of the 2013 event, and (ii) 1-2-metre-deep viscous debris flows (*malbā ānā*) generated by highly erosive sediment-laden discharges from gullies and torrent channels accumulating behind the Last Glacial moraine ridge off the left bank of the Mandākinī and ultimately tearing through the moraine crest to descend onto the now-inhabited riverside terrace in several channels, as it did during the 16-17 June 2013 event (see Fig. 5.38). The possibility of another lake outburst event from Chorābārī Tāl was discounted due to its already-ruptured moraine dam and empty basin. It must be acknowledged, however, that future interactions among the various hazards present in the landscape are extremely difficult to predict; they may play out in surprising ways, as they did during the June 2013 disaster. A future event may even involve currently unknown hazards such as the expansion of certain undetected subglacial lakes or the destabilisation of certain unexplored moraines owing to ice core thawing.

The loss and damage estimate associated with the relatively unextreme hypothetical situation considered above includes several hundred casualties as well as complete or partial destruction (despite protection from the newly constructed flood defences) of about one-third of the main Kédārnāth settlement (including, in particular, about 40 buildings located close to the Sarasvatī stream and a crucial bridge), the helipad by the Sarasvatī channel immediately upstream of the main Kédārnāth settlement, and about three-fourths of the new pilgrims' camp and the attached helipad, which are located on the previously mentioned riverside terrace off the left bank of the Mandākinī downstream.

Considering the complexities and uncertainties associated with the climate-related nexus of geohazards facing the UM community, the only tract of land around Kédārnāth that would appear safe for habitation is the 1-kilometre-long elevated terrace that runs along the extensive Last Glacial moraine ridge on the eastern side of the Mandākinī River, downstream of the new pilgrims' camp and helipad (see Fig 5.39). This flat, stable area was sensibly used to set up temporary tent camps in the months following the June 2013 disaster; however, the site was about 1.5-2 kilometres away from the main Kédārnāth settlement and temple, so the government abandoned it and chose the more proximate but much riskier current location below the scarred section of the Last Glacial moraine (see Figs. 5.21, 5.38). Moreover, despite its island-like high-risk setting between the two converging flood-prone headstreams of the Mandākinī, the main Kédārnāth settlement (see Fig. 5.23) has seen extensive and unprecedentedly rapid government-driven rebuilding (as well as aggressive marketing to upscale the pilgrimage economy to an unprecedented level) since the disaster. A new three-tier flood defence has been constructed at the upstream end of the settlement; however, its future is arguably uncertain in the face of climate warming-related risk escalation in an already hazardous periglacial environment that has a tremendous supply of extremely potent morainic and outwash sediments.

Fig. 5.30. Map showing the location of the Upper Mandākinī Basin research area in the Western Himalaya

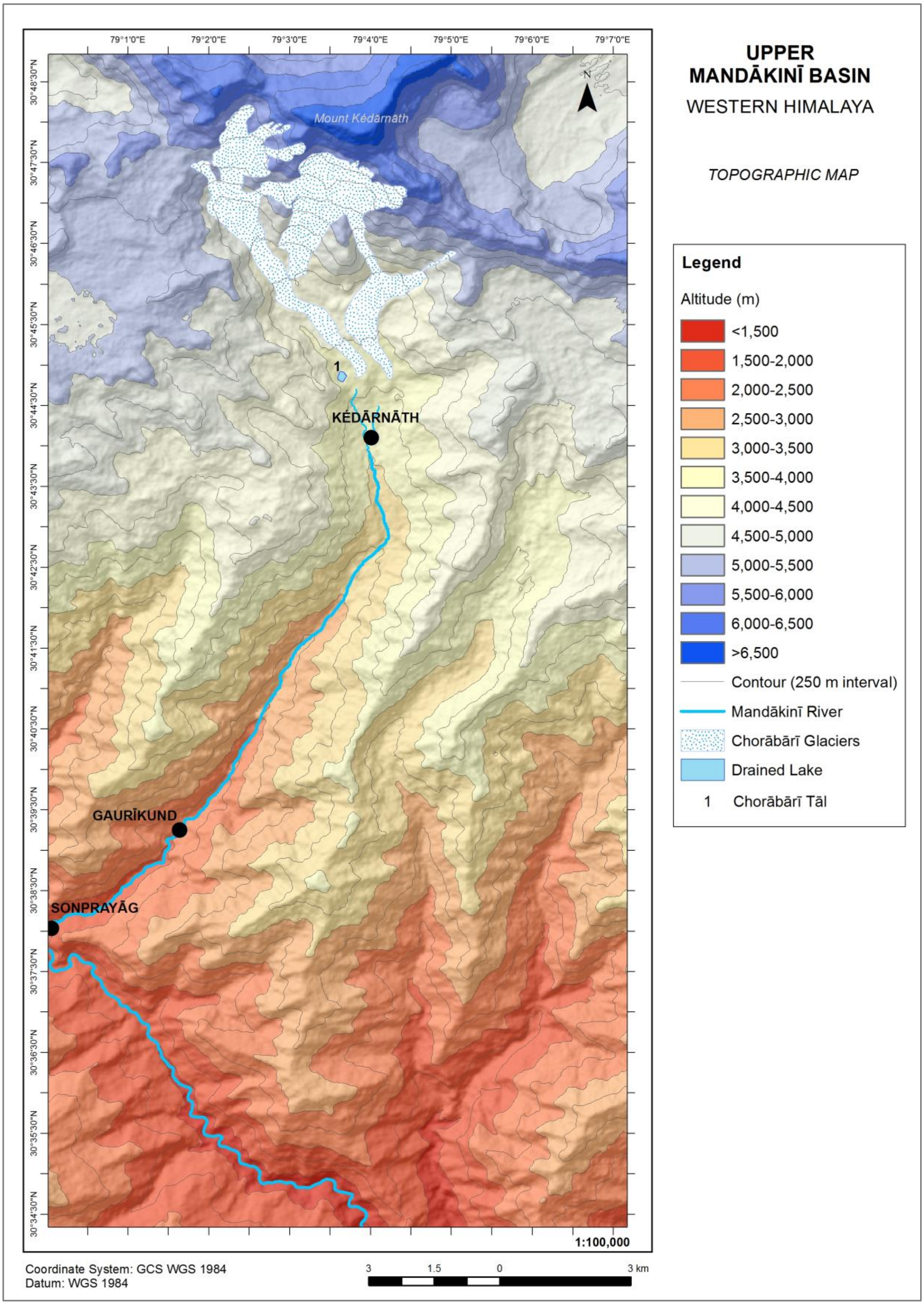


Fig. 5.31. Topographic overview map of the research area in the Upper Mandākinī Basin, Uttarakhand

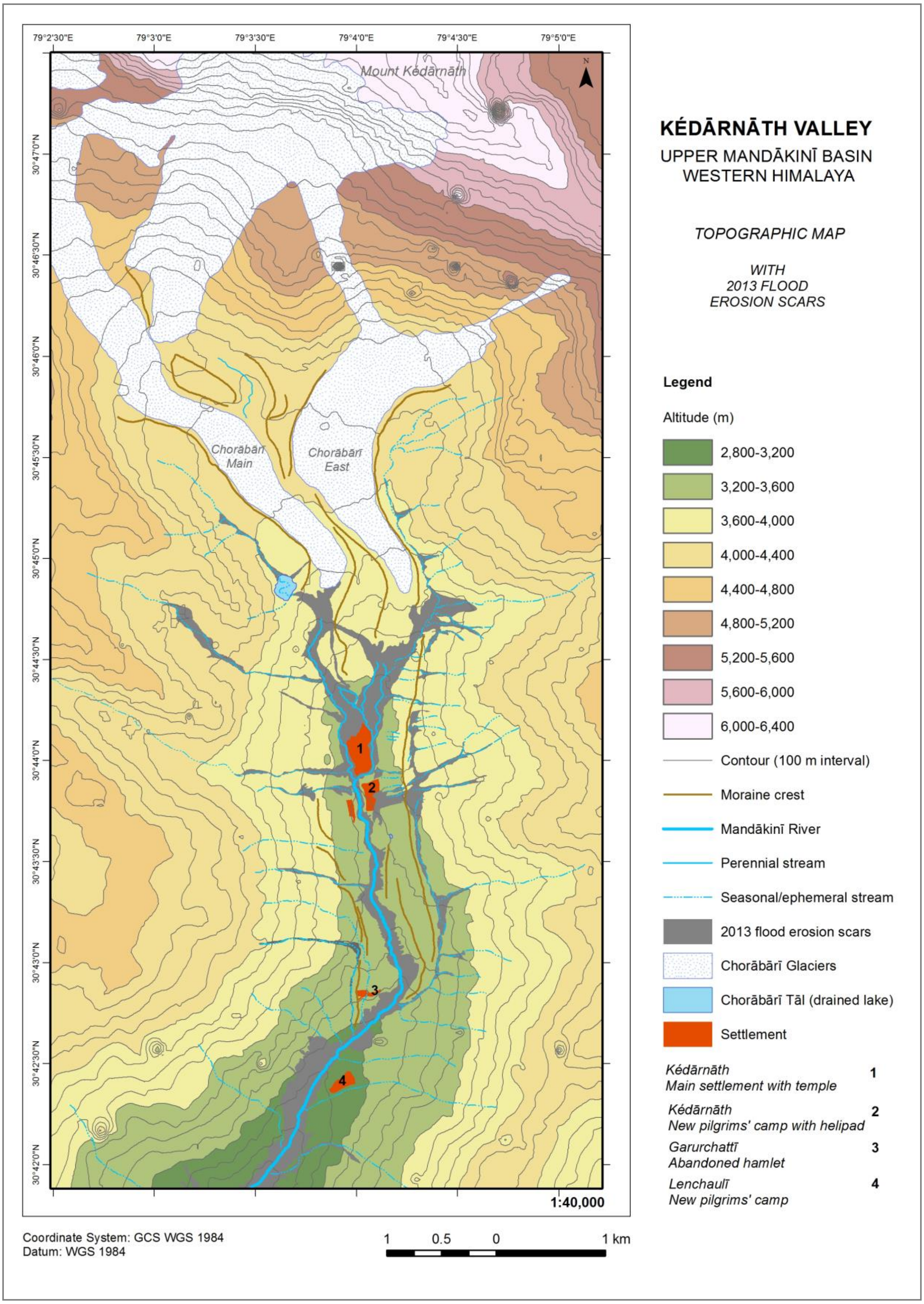


Fig. 5.32. Topographic map of the Kédārnāth Valley (with 2013 flood erosion scars), Uttarakhand

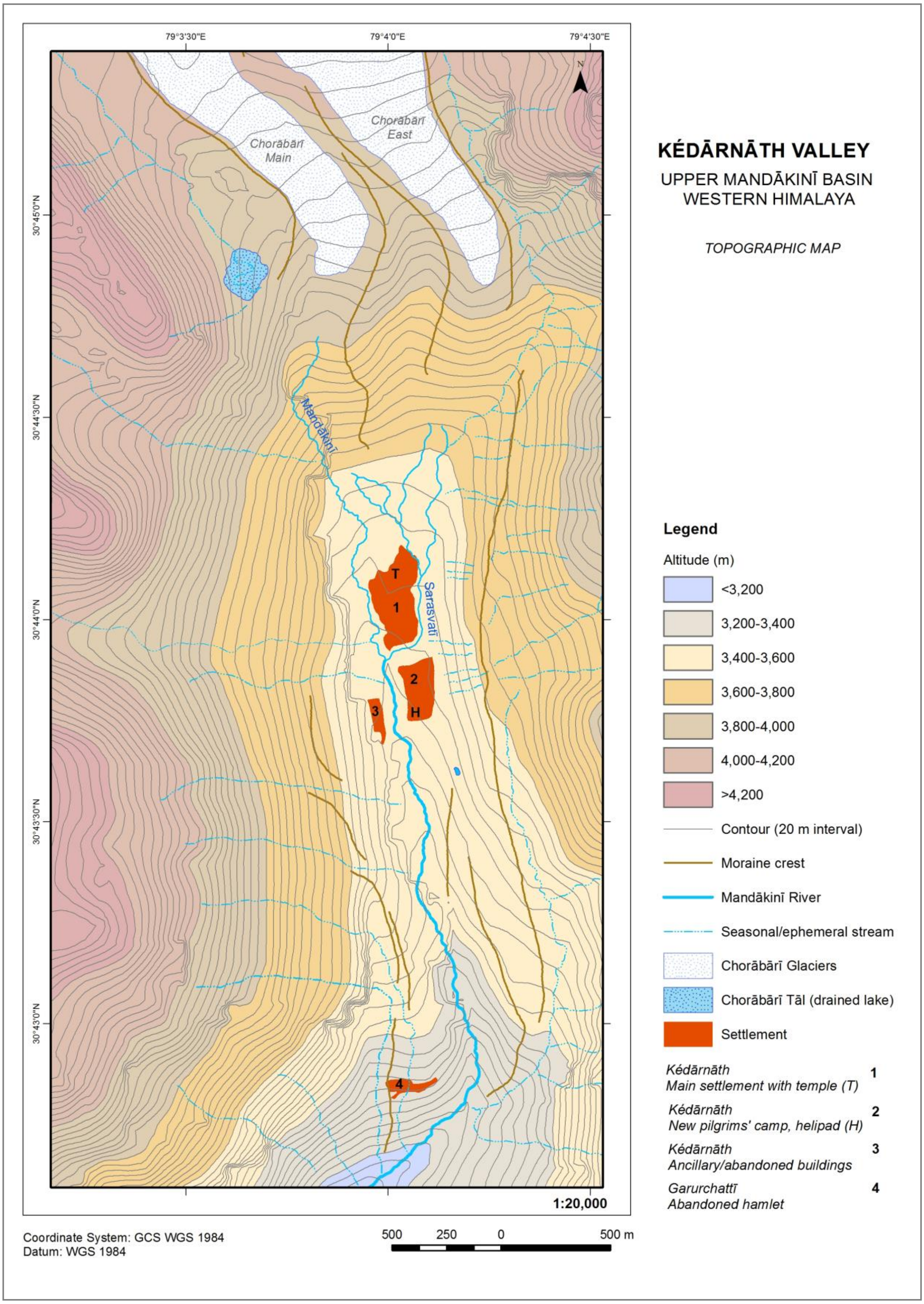


Fig. 5.33. Topographic map of Kédārnāth and the headwaters of the Mandākinī River, Uttarakhand

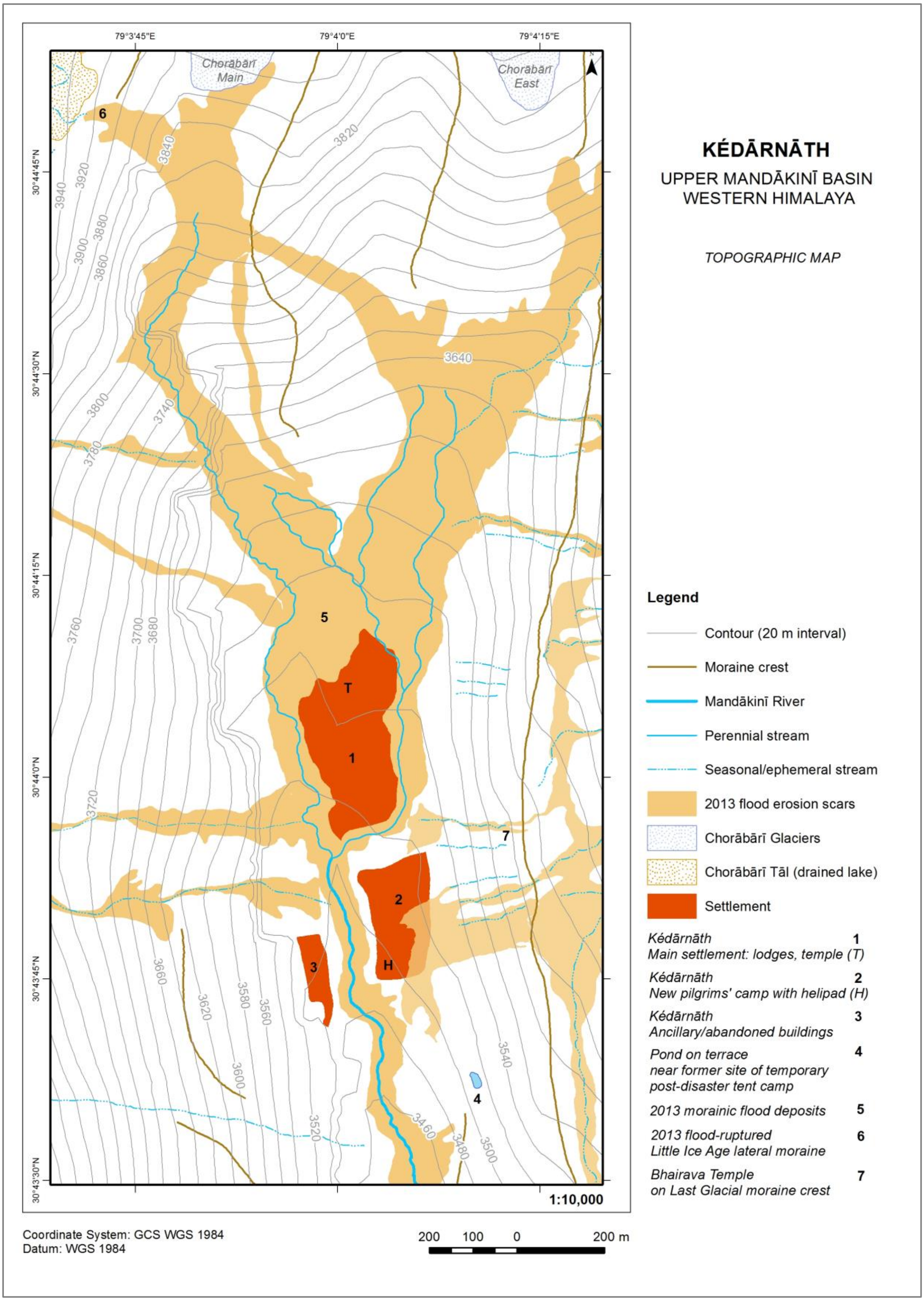


Fig. 5.34. Topographic map of Kédārnāth, Uttarakhand

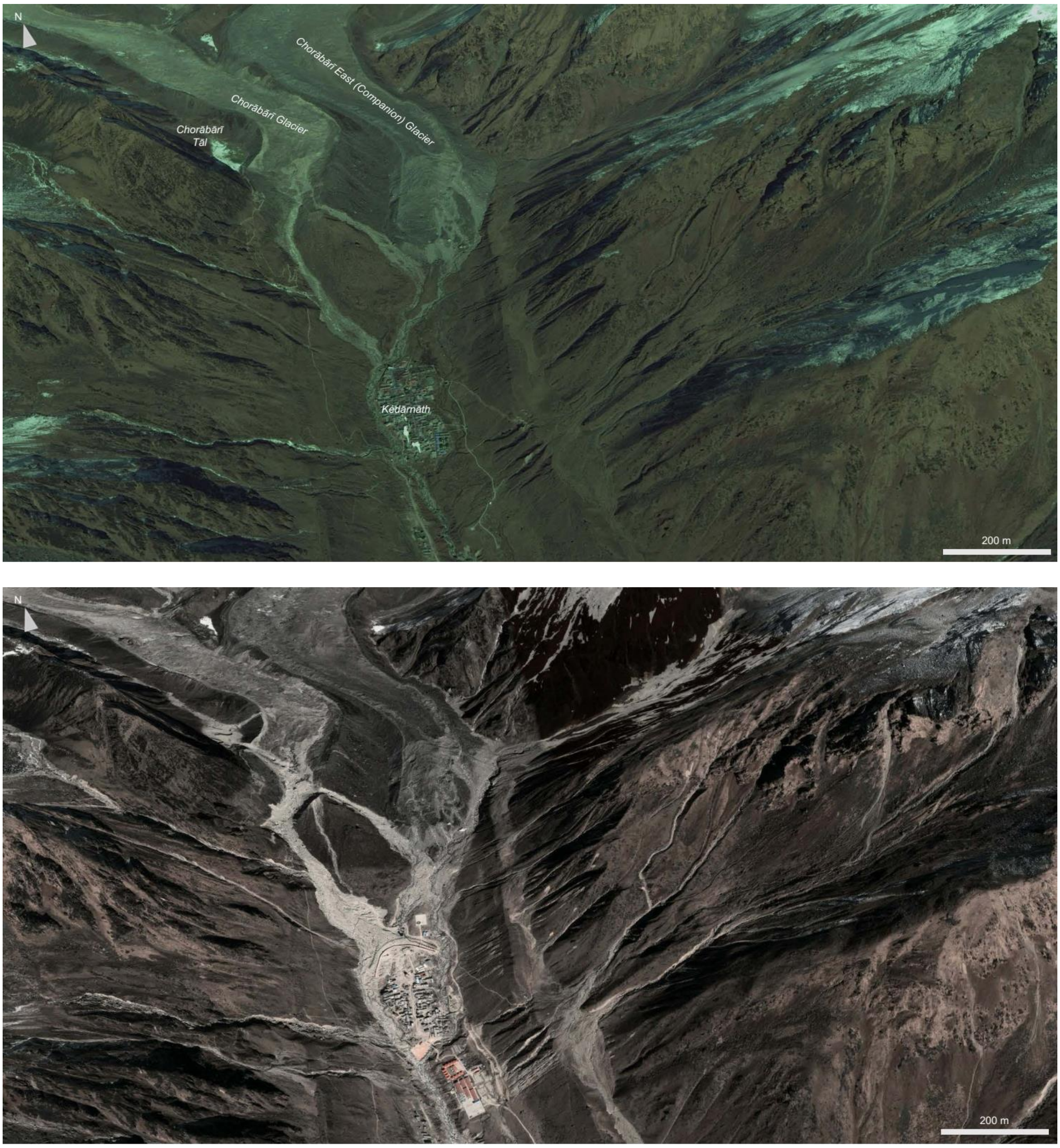


Fig. 5.35. Google Earth images (© CNES/Airbus, © DigitalGlobe): The head of the Mandākinī Valley (including the Chorābārī Glaciers, the Chorābārī Tāl lake, and the Kédārnāth settlement) before the June 2013 disaster (TOP image, captured on 2 December 2012) and 4.5 years after the disaster (BOTTOM image, captured on 14 November 2017: note the empty basin of the drained Chorābārī Tāl; geomorphic imprints of the two major debris flows that followed the Mandākinī and Sarasvatī stream channels and the associated sediment deposition over the flat Kédārnāth settlement area; and other erosional scars from the 2013 event, including the ones on the Last Glacial moraine immediately above the new red-roofed construction (pilgrims' camp) off the eastern bank of the Mandākinī River).

Fig. 5.36. Google Earth image (© CNES/Airbus, © DigitalGlobe) showing the head of the Mandākinī Valley (including the Chorābārī Glaciers, the empty basin of the Chorābārī Tāl lake, and the Kédārnāth settlement) six months after the disaster (on 14 December 2013): The arrows indicate the directions of the many precipitation-triggered flash floods/debris flows/mass movements that contributed to the devastation at Kédārnāth on 16-17 June 2013. A1-A6 mark the track of the 16 June 2013 flow that involved the Sarasvatī channel. B1-B12 mark the track of the 17 June 2013 flow associated with the Mandākinī channel, which involved the catastrophic drainage of Chorābārī Tāl (B3) after the lake-damming moraine was ruptured (at B4). C1-C9 and D1-D4 show the tracks of other flows that followed steep gullies and torrent channels on the eastern and western sides of the valley, respectively. C6-C8 mark the tracks of debris flows that tore through the Last Glacial Moraine ridge to arrive on the left-bank riverside terrace (C9), where a new pilgrims' camp has been developed since 2014. Specific locations have been referred to in the main text.

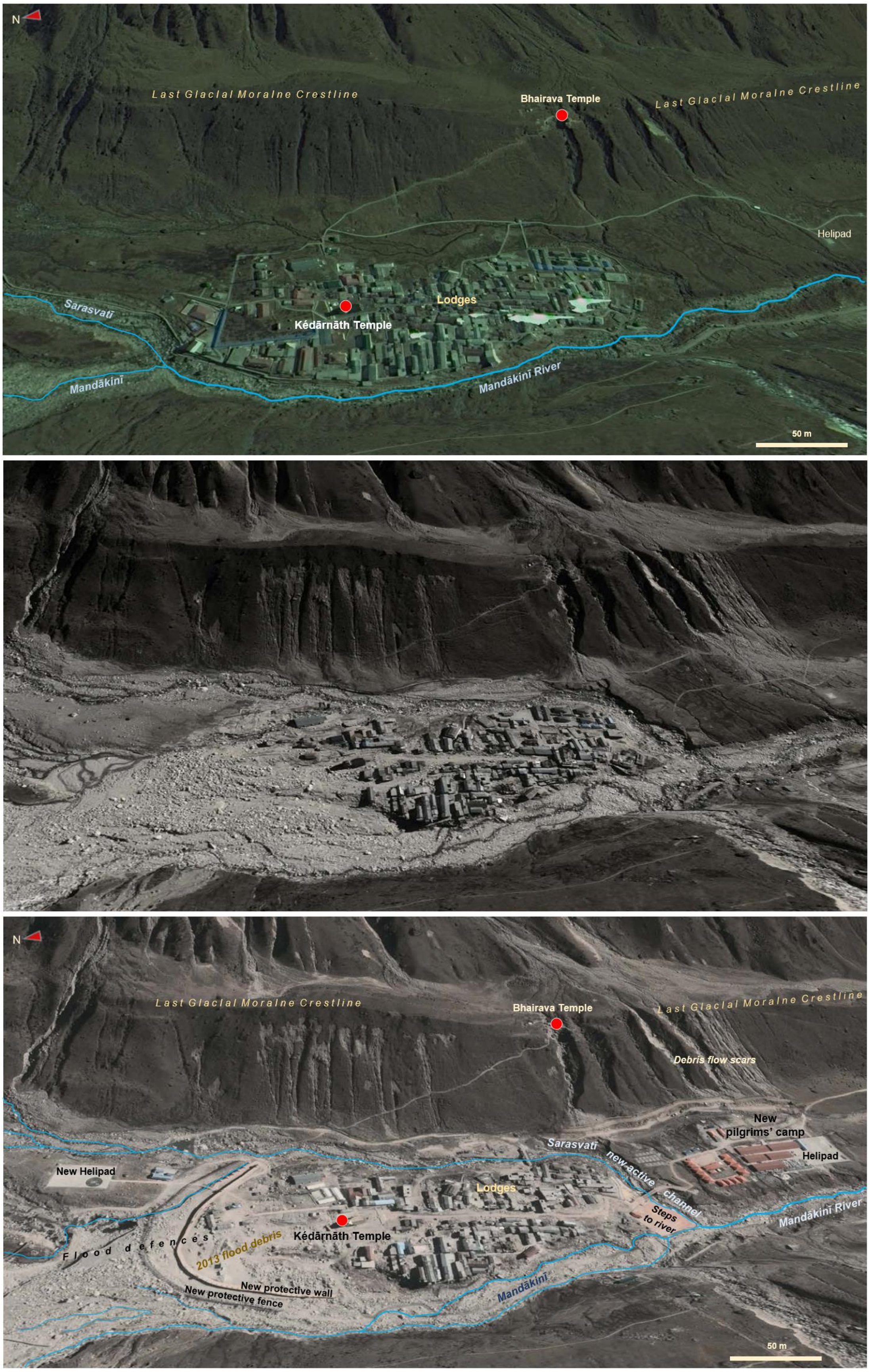


Fig. 5.37. Google Earth images (© CNES/Airbus, © DigitalGlobe): Kédārnāth before the disaster (TOP image, captured on 2 December 2012); six months after the disaster (MIDDLE image, captured on 14 December 2013, pre-reconstruction); and 4.5 years after the disaster (BOTTOM image, captured on 14 November 2017, reconstruction underway). Note, in particular, the changed course of the Sarasvatī stream.

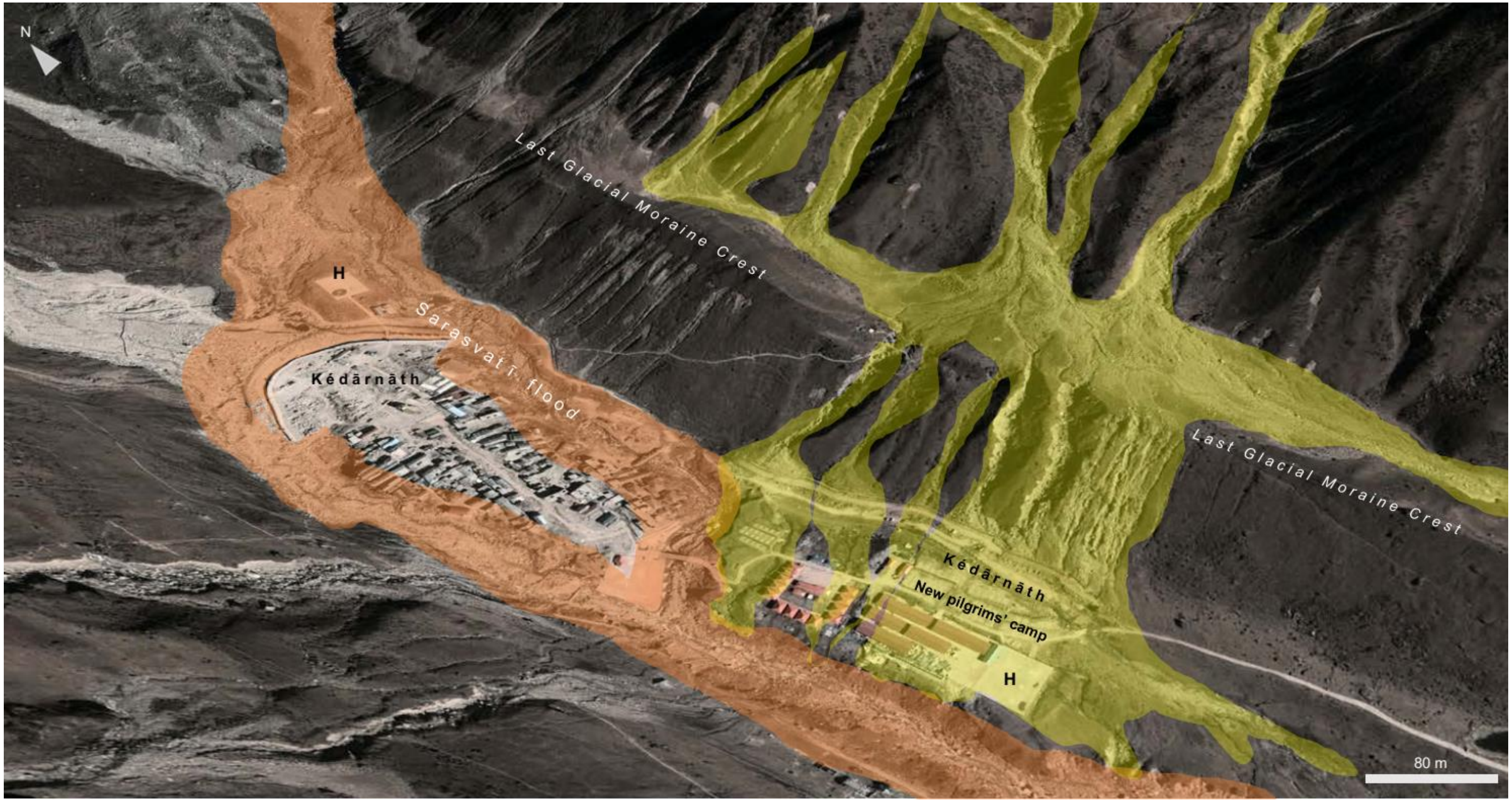
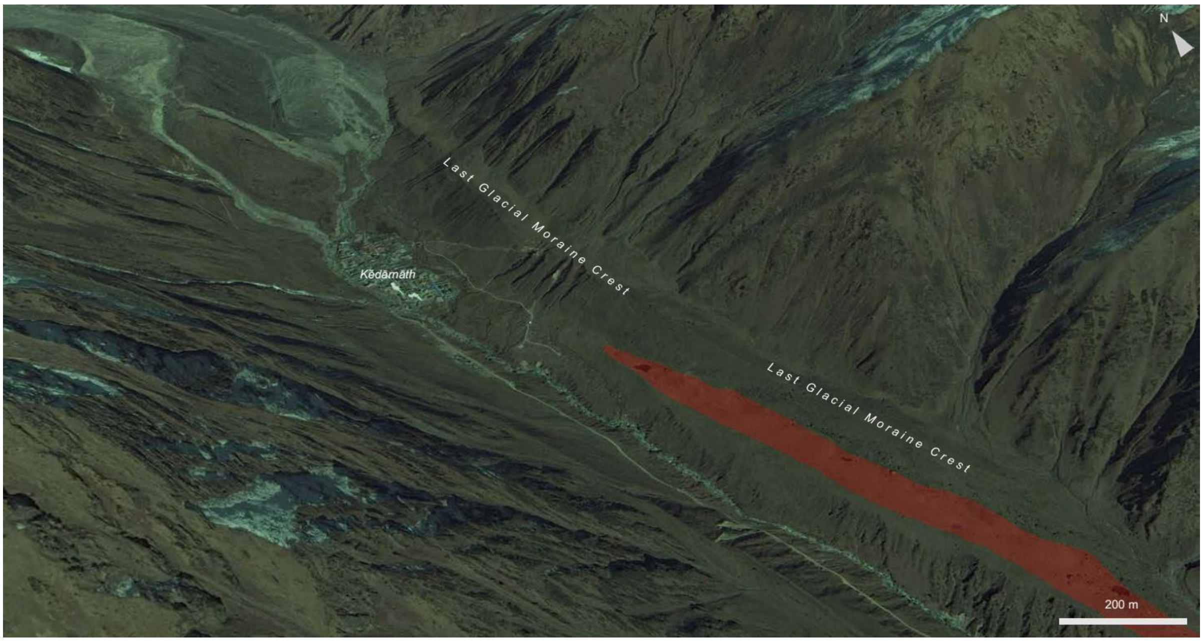


Fig. 5.38. Approximate, qualitatively determined hypothetical extents of (i) inundation and debris deposition at Kédārnāth in the event of a future extreme rainfall-triggered riverine flash flood (*nadī kī bārh*) along the Sarasvatī channel, similar to the initial 16th June component of the 2013 event, which has a flow depth of 3-4 metres (shown in *rust*) and (ii) debris deposition/runout from 1-2-metre-deep viscous debris flows (*malbā ānā*) generated by extreme rainfall-triggered erosive runoff along gullies/ torrent channels on the mountainside behind and above the Last Glacial moraine through which a combined flow breaks out in several channels, as it did during the 16-17 June 2013 event (shown in *yellow*)

Based on GPS-aided ground observations of active and inactive drainage channels and relief, DEM-based village-scale topographic mapping (Fig. 5.34), and participatory viewings of the landscape from vantage points with members of the community who witnessed the June 2013 disaster event [Base image: Google Earth (© 2018 CNES/Airbus)]



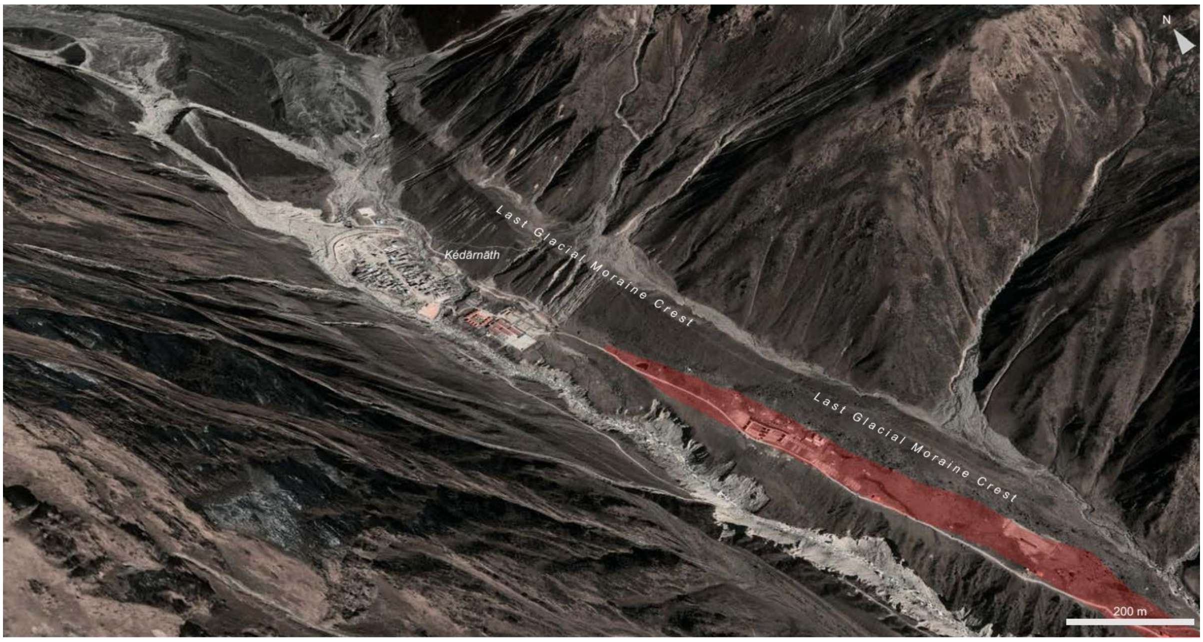


Fig. 5.39. Google Earth images (© CNES/Airbus): The head of the Mandākinī Valley (including the Chorābārī Glaciers, the Chorābārī Tāl lake, the Kédārnāth settlement, the section of the valley immediately downstream of it, and prominent Last Glacial moraines running along the eastern margin of the valley) before the June 2013 disaster (TOP image, captured on 2 December 2012) and 4.5 years after the disaster (BOTTOM image, captured on 14 November 2017, note the extensive erosional/depositional imprints of the disaster): The *red* patch covering the 1-km-long elevated terrace that runs along the extensive Last Glacial moraine ridge on the eastern side of the Mandākinī River shows the approximate extent of the only sites that were identified as safe for habitation following a qualitative geomorphological survey of the landscape and a review of published earth science literature on the June 2013 disaster.

Beyond, or rather beneath, the UM community's physical model of environmental hazards lies a culturally embedded metaphysical understanding of the processes that bring those hazards alive. The roots of this understanding are to be found in the religious legend of Kédārnāth, which portrays the site as a literal and figurative quagmire that utilises geophysically embodied energy from the *jyotirlinga* (radiant *linga* or phallic pillar resting on a *yonī* or vulvular pedestal, symbolising cosmic energy) of Lord Shiva, the Hindu embodiment of the Universe's destructive principle, to absorb *pāpa* (bad karma; vicious deeds and their merited consequences) and provide *moksha* (liberation from *samsāra* or the illusory world). A high priest narrates the story as follows (read with Figs. 5.40-5.42):

> *"Across India, there are twelve* jyotirlinga *[radiant phallic pillars of cosmic energy]. This is the Lord's eleventh* jyótirlinga, *the first one being at Somnāth by the Arabian Sea. It is called* svayambhū *[lit. self-manifested].* Nāth *[the Lord]* svayam *[himself] appeared here from the Earth in the form of a* linga *[phallic pillar]. The Lord's name is not Kédār… It is the place that is Kédār. In Sanskrit,* ké *refers to standing water… The land here has water underneath.* Dār *means "quagmire"… The land here is quicksand. That's why this place is called Kédār… When the Pāndava [five brothers from the epic Mahābhārata] slayed the Kaurava [their cousins], the* pāpa *[bad karma] of clan slaughter fell upon them. Determined to extinguish that* pāpa, *the Pāndava visited their teacher Lord Krishna [a form of Vishnu, the sustainer in Hinduism, as opposed to Shiva, the destroyer] and asked him how they could be relieved of the burden of the atrocities they had committed. Lord Krishna instructed them make a* yātrā *[journey] to the Himālaya [abode of snow]: "In the Himālaya, there is some place named Kédār. There, you will attain a* darshan *[holy glimpse] of the Lord." The Pāndava brothers asked, "But where will we find the Lord? How will we get there? Any directions?" Lord Krishna replied, "Proceed towards the snowy mountains, and there you will attain a* darshan*." The Pāndava eventually arrived at a place called Guptakāshī [lit. 'Secret Kāshī'; Kāshī is the ancient name of Vārānasī, a sacred lowland town on the Ganges], where there is a temple dedicated to Vishvanāth [lit. 'Lord of the World', Shiva]. Until about three decades ago, all pilgrims used to halt there to pay their respects to the place where Lord Shiva is believed to have given a* darshan *in his secret form. But as the road moved up the valley, all these places on the way began to be overlooked… Anyway, after that the Pāndava arrived here [in Kédārnāth]. It was here that the Lord gave them a full* darshan *in his famous buffalo form. When Lord Shiva assumed the form of a male buffalo, the Pāndava found thousands of buffaloes here. Among the five Pāndava, Yudhishthira was the wisest and Bhīma was the strongest. Yudhishthira exclaimed, "What sort of place is this, where there are no people, only bulls! Surely the Lord is here and he is testing us." He commanded Bhīma, "O powerful one, spread your legs apart and place them on these two great mountains, Méru and Suméru [whence the two Chorābārī Glaciers descend southwards and two tributaries of the Gangotrī Glacier descend northeastwards]. I will push each of the bulls between your legs and out. Only those that are not the Lord will pass under the legs of us sinners; the one that is the Lord himself will never do so!" The Lord's* linga *was already there, but the Pāndava were oblivious of its presence… One bull retreated, so the Pāndava started running after him. Ultimately, that bull arrived at the* linga *that is still worshipped today. He tried to hide under the* linga, *but Bhīma held him by the tail, and said, "O Lord, where are you trying to hide?" Then there was an* ākāshavānī *[lit. 'sky-speech', divine revelation]: "O Pāndava, this is my* svayambhū jyotirlinga*. The hind of my body has become part of this, while my head has gone to Pashupatināth [in Kathmandu, Nepal]. My head will be worshipped there and my hind here. Massage my back with* ghee *[clarified butter]; then erect a temple for me. Thereafter, you will attain liberation." So the Pāndava constructed this magnificent temple, and then all of them attained* moksha *[liberation]. That is why this place is also called Mokshadām [liberator]. It is written [in Sanskrit] that even great deities shall find it extremely difficult to reach this place. It is also written that any* pāpa *[bad karma] accumulated elsewhere is extinguished right here, but if somebody still commits a vicious act here, then they have no way out."*

The above legend plays a key role in shaping the UM community's geographical imaginations of the metaphysical. Figs. 5.40-5.42 spatially elucidate these imaginations as traditional cultural models of a sacred Hindu geomorphology that is centred around the physical landscape of Kédārnāth and the headwaters of the Ganges, but spans the entire Indian subcontinent.

The destructive potential of Kédārnāth's physical landscape lends it an awe-inspiring character, making it an ideal location for penance and redemption. Facing the rugged, perilous mountains is meant to be an outward manifestation of the seeker's inward strife against vice and fear - a *yātrā* or journey that leads the self "from untruth to truth, from darkness to light, and from death to immortality" (Brihadāranyaka Upanishad: 1.3.28). Every hazard, therefore, is to be regarded as a sacred opportunity for the cultivation of moral virtue and, through that, the attainment of psycho-spiritual liberation from all forms of vulnerability. According to this philosophy, when all inner vulnerabilities are completely overcome or extinguished, so are all outer hazards; a shift in consciousness leads to a shift in reality. The *yātrā*, in both its inner and outer dimensions, comes to fruition at the climactic moment of *darshan* ('holy glimpse', lit. 'vision'), when the consciousness is so transformed that the *darshak* (lit. 'viewer', subject, inner world) and the *drishya* (lit. 'view', object, outer world) dissolve into each other to bring about the realisation of one all-encompassing reality. The *yātrā* is indeed life in a world full of hazards, and *darshan* is salvation. *Darshan* is ultimately the discovery of the true self (*ātman*), which is equated with, and often outwardly celebrated as, the realisation or coming of "God", or rather *brahman,* the ultimate cosmic reality in Hinduism, in a certain beloved worldly form or even without any form. It is expressed emotionally as a state of bliss.

Somésh, a priest in his forties who narrowly escaped being buried alive during the 2013 disaster, exclaims:

> *"The massive Kédārnāth mountain, the snow on its slopes, the glaciers coming down, all the stony rubble… that mess of boulders and ice and sand… with God-knows-how-many pools of water underneath.... all these scarred nullahs [steep mountain torrent channels]… the river… the huge scars along the river… all the landslides… the cloudy sky… isn't everything here a hazard? Monsoon rain tends to be so angry these days that the whole valley turns into a great hazard. But we have to live here… And we should live here without fear, because Lord Shiva lives here. The cosmic phallus will give us strength…"*

That Somésh and his community "have to live here" and "should live here without fear, because Lord Shiva lives here" is a reverential invocation of the spiritual opportunities afforded by the geophysical hazards that operate in the valley. Any future disaster, Somésh believes, will be a test of the community's collective faith and moral fortitude; deliberately becoming unexposed to the hazards by means of relocation "would amount to pusillanimity".

Nearly all interviewees (28 of 30) directly or indirectly interpret the 2013 debris flow disaster as a case of divine retribution associated with the *prakopa* (punitive wrath) of Lord Shiva. More than half of these individuals (17 of 28) believe that the community karmically deserved, or rather earned, the disaster, or that it was morally necessary for the community to face it; there was no alternative cure for the growing materialistically inspired lack of virtue, not only among local residents, but also (and, according to the majority of interviewees (10 of 17), *particularly*) among seasonal pilgrims and immigrant workers.

Most interviewees (19 of 30) go on to suggest that sensory gratification derived from excessive material consumption causes a build-up of *pāpa* (bad *karma*, vice, moral pollution) in the collective consciousness of the community and analogous hazardous physical energy (such as atmospheric heat) in its environment. This accumulation of *pāpa* can often only be arrested and replaced with *punya* (good *karma*, virtue) through a compassion-inspiring purgative natural calamity catalysed by divine retributive intervention when a certain moral threshold is crossed. The 2013 disaster is widely believed to have been such an event; it has been referred to as a *daivīya āpadā* or divinely ordained calamity even by the modern, secular state. In the above karmic causal explanation for the disaster, *pāpa* that is accumulated through excessive material consumption could arguably be regarded as the spiritual equivalent or "sublimated" form of anthropogenic environmental degradation (including, for example, dangerously heightened atmospheric greenhouse gas concentrations at the global level and unsustainable construction at the local level), which obviously remains on the earthly plane. Moreover, the notion of *pāpa*-based thresholds for purgative calamities is arguably analogous on the earthly plane to the "tipping points" or "tipping cascades" that characterise environmental risk in the discourse on the Anthropocene (see Lenton et al. 2008, Steffen et al. 2007, 2018; Crutzen 2006, 2002).

Young, priestly Vishnu, who was a pilgrims' muleteer at the time of the 2013 disaster, eagerly explains:

> *"I think the disaster happened because of the* hāé *[curse] that arose from pilgrims' anguish… The overpricing here… Pilgrims who arrived in Gaurīkund at night wouldn't be allowed to go up and all the rooms there would be full… So, to take advantage of the situation, people would take four, five, ten thousand rupees and make them sleep just anywhere. So pilgrims were being harassed… Sometimes pilgrims on the trail were intentionally pushed and made to fall… And there were just too many excesses in Kédārnāth… Overpricing, priests who would drink before visiting the temple, and some pilgrims were so sick they would go to Kédārnāth with bottles of alcohol, chicken, etc., and just have a party… I think this is the reason."*

Govind, a middle-aged priest and contractor, adds rather fervently:

> "*Some Népālī workers and even educated pilgrims from big places were depraved… girls and all… they were involved in businesses of that sort… And then chicken, meat, beer bottles, gambling, angry shouting, and all kinds of misbehaviour – people had made a complete* tamāshā *[mockery, spectacle] of the pilgrimage. If you want to have a wild, obscene picnic, why don't you go to Bombay, Goa, America? This is a divine land… no meat, no rubbish will be tolerated here!"*

In offering the above moral judgments as karmic causal explanations for the geophysical hazards that resulted in the 2013 disaster, both interviewees seem to be claiming the high ground of righteousness and chastity on account of their "pure" birth and conduct as supreme-caste Brahmin[4] males in "one of the most sacred parts of the country, and indeed the world". In the wider priestly community, the strongest expressions of disdain and disgust are evoked by flesh eating, which is widely regarded as a karmically punishable offence, particularly if the flesh is bovine, in which case the act may be more morally reprehensible than murder. Owing to the holy status of cows in Hinduism, killing them is not only socially controversial but also a criminal offence in most Indian states, including Uttarakhand; legal restrictions on cow slaughter are a subject of heated debate between Hindu nationalists and secularists across India. Political commentary on flesh eating has included claims about its moral causal relationship with natural calamities. For example, during a monsoon flooding disaster in August 2018 that affected several million people across the Communist-ruled province of Kerala where cow slaughter is legal and beef is widely consumed, a legislator from the Hindu nationalist Bharatiya Janata Party remarked that

[4] Brahmins (Sanskrit: *Brāhmana*) are members of the priestly and scholarly hereditary caste, who still occupy the pinnacle of the oppressive caste-race hierarchy in traditional Hindu societies.

the calamity had occurred within a year of a beef festival being held in the province and was divine punishment for cow slaughter in a land known as God's own country (Pinto 2018, TNN 2018).

Although female interviewees generally exhibit more humility in their speech and tend not to place themselves at moral vantage points, they do identify materially more advanced and therefore morally "more polluted" lowland societies as a source of *pāpa* (vice), which karmically elicits divine punishment by means of geophysical hazards. They express a particular interest in how communities that lose their piety and austerity to material ambitions bring destruction upon themselves.

Bidyā, a Brahmin housewife in her twenties, remarks in a deep, solemn voice:

> *"The disaster was God's doing. He wanted to teach us a lesson. We were punished so that those of us who are left reform ourselves… have good thoughts, go to the Lord's temple and express our devotion through hymns, remember His name, stop harassing others… be content with one* rotī *[piece of bread] instead of two, be happy with five rupees instead of ten… I mean, earn your bread by the sweat of your brow, and don't trouble anyone. Try not to stoop to the level of the lowlanders."*

Hariyālī, another young Brahmin housewife, concurs:

> *"Our people, especially the menfolk, have changed completely… They used to be simple and pious until mobile phones came. Now they've become greedy…. They want to live like city folk, plains folk… That's why the disaster happened… It is very simple: Our people soiled the purity of these sacred mountains, so the mountains made a mess of them. We deserved the disaster… It was very unfortunate, but it had to happen…"*

For Hariyālī, the contamination and the merited penalty are not merely moral, but also eco-spiritual. She attributes the disaster (as well as the geophysical hazards that induced it) to unsustainable material growth driven largely by male ambition, unsustainability being conceptualised both spiritually and environmentally. Her idea finds an echo in the lodge caretaker Jagdīsh's remark about the need for "Man" to know his limits:

> *"We must have gone against the Lord's decree… As we sow through our deeds in Kédārnāth, so we shall reap by the Lord's grace. There is a big difference between the Lord's thinking and Man's. If Man starts to become God, calamity will surely come."*

All examples of disaster-deserving moral excesses provided by the interviewees fall into ten traditionally specified categories of *adharma* (vice, the antonym of *dharma* or righteousness), of which local male Hindu priests express a substantial awareness: *amānavatā* (inhumanity), *anyāya* (injustice), *ahamkāra* (egocentricity), *svārtha* (selfishness), *mada* (vanity), *moha* (delusion, leading to temptation), *kāma* (lust), *lobha* (avarice), *mātsarya* (envy), and *krodha* (rage). "*When we stray from* dharma, *then… as is written in the great scriptures,"* the imposing priest Umāpati and his senior colleagues stand up and pronounce in a unified voice, "*as long as* dharma *continues to be harmed, ruin is what will become of us…"*

A deeper ethnographic engagement with everyday conversations on *adharma* or unrighteousness reveals that all of its ten varieties listed above are in fact widely regarded as symptoms of materialistindividualist-consumerist modernity. Modernisation, urbanisation and "Westernisation" therefore become threats, or rather *hazards*, to *dharma*, the righteous way of life as defined in the classical Sanskrit language by the "noble sages" of *satyuga,* the glorified ancient epoch of truth.

Some of those who attribute the disaster and the causative geophysical hazards to karmic retribution (5 of 28) also present other subsidiary, ostensibly non-moral but modernisation-related (and therefore arguably implicitly moral) causal explanations such as the perceived physical impact of helicopters on slope stability:

> *"Ever since this helicopter service was started, everything from the environment to arrangements for pilgrims… everything changed tremendously… It was a damaging change… A destructive change has set in… Besides all our evil deeds, the cause [of the disaster] was precisely this. The helicopter service was the main cause… The vibrations are weakening the mountains, and there is an atmosphere of irritability and chaos…"*

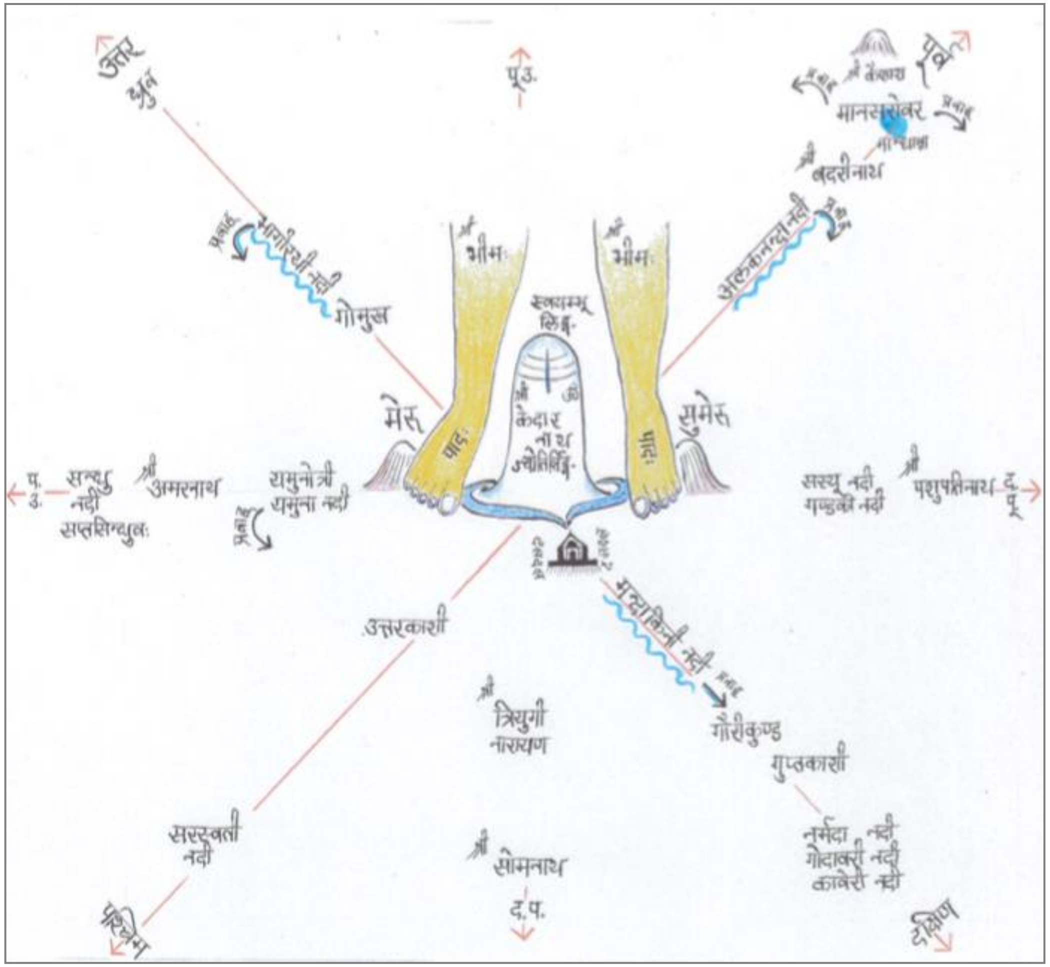
Interestingly, more than half of all interviewees (16 of 30) express vague suspicion or contempt towards the helicopter service; they seem to regard it as an eco-spiritually disruptive and morally problematic phenomenon in that the modern materialistic "self-indulgence" and "blaring" industrial mechanicality it embodies jeopardise the traditional view of pilgrimage as pacific penance or as a device for contemplatively cultivating austerity through submissive exposure to the elements. The contempt also seems to stem from their pride in the traditional lack of materialistic "contamination" in highland societies and their view of the helicopter as a potent and highly symbolic vector of geophysically punishable karmic vice born of the "low"-lands. The helicopter service may therefore be seen a key marker of modernity's "assault" on the traditional society, around which wider anxieties about socio-environmental change seem to be gathering.

As the ultimate source of consumptive vice, modernisation then emerges as the ultimate hazard – the source of all the bad *karma* that generates disasters such as the one that ravaged the UM valley in June 2013. Consequently, turning the tide on materialist-consumerist modernity and its moral impact on society must somehow lead to the mitigation of natural hazards. This traditional idea may at first seem absurd from a Western/modern scientific standpoint, but it happens to be functionally consonant with the understanding that climate change-related hazards and other environmental challenges of the Anthropocene are products of unsustainable natural resource consumption. After all, it is not difficult to argue that unsustainable development is driven by the "unbridled" modernity-inspired growth of the human desire for material comfort ("satiation of the senses"). For example, a comfortable ("vicious") fossil fuel-powered helicopter ride does have a far greater environmental/carbon footprint than an arduous ("virtuous") trek to the pilgrimage site. Moreover, even though the modern scientific ontology of the above process is entirely geophysical and amoral (as opposed to the traditional karmic model of causality), modern science-based appeals for safeguarding the planet's future do still tend to moralise resource consumption. However, it would be a mistake to think that traditional moral and modern scientific understandings of environmental dynamics can always work synergistically. For instance, earthquakes usually cannot be linked even remotely to human consumption by Western science, but are still thought by the community to be karmically responsive to consumptive vice.

Indeed, the UM community's traditional moralised/spiritualised metaphysics of geophysical risk presents a stark epistemic contrast to the modern or Western scientific materialist view of causality in environmental dynamics (see Table 5.3). This contrast generates conflicting objectives vis-à-vis human interaction with environmental hazards. Whereas the former worldview is concerned with facing hazards for the preservation and cultivation of moral virtue and spiritual freedom, the latter is concerned with avoiding or mitigating them for the preservation and cultivation of material abundance. Although the two worldviews seem, and probably are, irreconcilable, they have somehow been synthesised (if not harmonised) within almost every interviewee's mind, leading to an aspirational dualism that implies that spiritual and material goals are often pursued concurrently and in conflict with each other.

With rapid social change, modern science-inspired physical and amoral understandings of nature are certainly gaining wider psychological acceptance; however, the doctrines of *karma* and *dharma* seem so deeply and firmly entrenched in the mass psyche that any metaphysical convictions based on them are very difficult to challenge, let alone uproot. In fact, the June 2013 "divinely ordained" disaster and other extreme environmental events in recent years seem to have played a very significant role in reinforcing and hardening the UM community's traditional moral/spiritual associations with geophysical hazards.

Fig. 5.40. A participatory sketch map representing the Kédārnāth priestly community's folkloristic model of the regional physical landscape (based on inputs from 11 interviewees)



The diagonal axes show the cardinal directions – North at the top left corner, East at the top right, South at the bottom right, and West at the bottom left. Located at the centre of the map, the *svayambhū* (self-manifested) *jyotirlinga* (radiant cosmic phallic pillar) represents the **Kédārnāth** mountain, an abode of Shiva. The legendary mountains **Méru** and **Suméru** (which correspond to physical present-day mountains) are shown on its left (northwest) and right (southeast) respectively, with Bhīma's right foot (corresponding to the location of a physical present-day trough of a glacier) placed between the Kédārnāth and Méru mountains and Bhīma's left foot (corresponding to the location of a physical present-day trough of another glacier) placed between the Kédārnāth and Suméru mountains. **Gangā** Maiyyā or Mother **Ganges**, the holiest river in Hinduism, is believed to have descended from Shiva's locks, which are reflected in the physical landscape, according to some priests, as a complex network of heavily glacierised valleys. The three main headstreams of the Gangā – **Bhāgīrathī**, **Alakanandā**, and **Mandākinī** – are shown emerging, respectively, at **Gómukh** (or Gaumukh, lit. 'Cow's Mouth', the snout of the Gangotrī Glacier) in the north, near **Badrināth** (one of the holiest pilgrimage sites dedicated to Vishnu, the embodiment of the Universe's sustaining principle, who binds the self to material existence) in the east, and at the temple of **Kédārnāth** (one of the holiest pilgrimage sites dedicated to Shiva, the embodiment of the Universe's destructive principle, who liberates the self from material existence) in the south. In the northwestern direction, far beyond the Méru mountain, are: **Yamunótrī**, a pilgrimage site near the source of the **Yamunā**, the holiest tributary of the Gangā; **Amarnāth**, a High Himalayan pilgrimage site in Kashmir that is a holy cave with an ice stalagmite *linga* associated with Shiva; and the holy **Sindhu** or **Indus** river system, comprising seven legendary rivers known as the **Saptasindhuvah**. In the southeastern direction, far beyond the Suméru mountain, are: the holy Himalayan rivers **Saryu** and **Gandakī**, both tributaries of the Gangā; and **Pashupatināth**, a sacred Shiva pilgrimage site in Nepal's Kathmandu Valley. Along the western axis, far beyond the sacred town of **Uttarkāshī** (lit. 'Kāshī of the North', where Kāshī refers to the lowland city of Vārānasī, a *jyotirlinga* site on the banks of the Gangā and one of the holiest places in Hinduism), are the headwaters of the legendary holy river **Sarasvatī** (not to be confused with one of the headstreams of the Mandākinī). In the southwestern direction, far beyond **Triyugīnārāyan** (the sacred site of the cosmic marriage between Shiva and Pārvatī), is **Somnāth**, another *jyotirlinga* and Shiva pilgrimage site located by the sea in the western Indian state of Gujarat. Along the southern axis, far beyond the sacred sites of Kédārnāth, **Gaurīkund** (lit. 'Gaurī's Pond', a sacred site associated with Shiva's consort Pārvatī) and **Guptakāshī** (lit. 'Secret Kāshī') in the Mandākinī Valley are the central and southern Indian holy rivers **Narmadā**, **Godāvarī** and **Kāvérī**. Along the eastern axis, far beyond Badrināth, are the placid holy waters of **Mānasarovar** (lit. 'Mind Lake' or 'Lake of Consciousness', a Shiva pilgrimage site believed to be an axial point associated with the origins of three great river systems – the westward-flowing Sindhu or **Indus** (including its tributary Sutlej), the southward-flowing Gangā or **Ganges** and the eastward-flowing **Brahmaputra**) on the Tibetan Plateau, beyond whose northern shores lies the great holy mountain **Kailāsa** (Kailāsh), the ultimate abode of Shiva and Pārvatī.

The above image and caption should be read in conjunction with the account of the religious legend of Kédārnāth and Figs. 5.41-5.42.

Fig. 5.41. Google Earth image (© 2018 CNES/Airbus, © 2018 DigitalGlobe): looking northeast towards the terrain around the Kédārnāth mountain (see also Fig. 5.40)

On the northeastern side of the Kédārnāth massif, the extensive Gangotri Glacier runs northwestwards and then northwards to the origin of the Bhāgīrathī, a key headstream of the Ganges. The trough between the Méru and Kédārnāth mountains and that between the Kédārnāth and Suméru mountains are occupied by northeastward-flowing glaciers that are tributaries to the Gangotri Glacier. On the southwestern side of the Kédārnāth massif, the twin Chorābārī Glaciers descend southwards to release the Mandākinī, another key headstream of the Ganges. The red dot shows the location of the temple and settlement of Kédārnāth.

Fig. 5.42. Google Earth image (© 2018 CNES/Airbus, © 2018 DigitalGlobe): looking east from over the Kédārnāth mountain (see also Fig. 5.40)

The Gangotri Glacier flows westwards from the Chaukhamba massif and veers northwards past the Kédārnāth massif to arrive at its terminus beyond the Shivling mountain. Using the Kédārnāth mountain as the point of reference, (i) the Méru, Kédārnāth and Suéru mountains are located roughly along a northwest-southeast axis that runs broadly parallel to the Gangotri Glacier; (ii) the terminus of the Gangotri Glacier (the origin of the Bhāgīrathī,, a key headstream of the Ganges), the Kédārnāth mountain, and the termini of the southward-flowing twin Chorābārī Glaciers (the origin of the Mandākinī, another key headstream of the Ganges) are located roughly along a north-south axis; (iii) Kédārnāth, the terminus of the eastward-flowing Bhāgīrath Kharak Glacier (the origin of the Alakanandā, another key headstream of the Ganges), and the Mānasarovar Lake on the Tibetan Plateau are located roughly along a west-east axis. The red dot shows the location of the temple and settlement of Kédārnāth.

Table 5.3. A comparison of Western scientific and local traditional understandings of the complex, precipitation-related debris flow hazard present at Kédārnāth

Description of the geomorphic hazard		Qualitative likelihood of occurrence		Key interacting hydroclimatic change signals and their implications for the hazard		Potential impact on the community at Kédārnāth	
Western scientific interpretation	Local traditional interpretation	Western scientific view	Local traditional view	Western scientific knowledge	Local knowledge	Physical	Metaphysical
Extensive viscous debris flows, rich in entrained morainic and outwash boulders and gravel, generated by high-intensity rainfall through multiple interacting mechanisms, including: (i) flash floods and mudflows originating in gullies and couloirs (possibly snow-filled) that drain into steep (often ephemeral or seasonal) mountain torrent channels that eventually join the Sarasvatī or the Mandākinī stream; (ii) extremely rapid meltwater discharges from glacier outbursts, englacial, subglacial or supraglacial meltwater pools, or pools dammed between mountain fronts and lateral moraines – all associated with the Chorābārī Glaciers; (iii) the Sarasvatī and/or Mandākinī streams overflowing their banks and the ensuing flash floods entraining glacial outwash sediments; and (iv) excessive runoff from mountain slopes accumulating unsustainably behind the crest of the high Last Glacial moraine that runs along the eastern margin of the valley, and then tearing through the moraine to entrain its sediments while descending rapidly into the valley perpendicular to the main Sarasvatī/Mandākinī channel [FO]	Clouds exploding to generate extreme stream discharges and extensive debris flows (*'dhartī ākāsh ék honā'*, lit. 'sky and earth becoming one') in ways similar to those described by Western science, except that the hazardous geophysical energy involved is an expression of karmically earned, morally purgative divine retribution associated with the *prakopa* (punitive wrath) of Lord Shiva, which embodies a build-up of *pāpa* (bad karma, vice, moral pollution) in the collective consciousness of the community as a result of sensory gratification derived from excessive material consumption [CI/E]	Highly likely in summer, especially during pre-monsoon storms that interact with strong local convection or/and extratropical upper-air depressions in June as well as throughout the rainy monsoon season (July-September); a slight reduction in the hazard since the June 2013 catastrophic drainage of the Chorābārī Tāl lake, which has since remained empty due to the rupturing of the moraine that had previously dammed its waters [FO]	Likelihood dependent on whether the community (including seasonal pilgrims and immigrant workers) collectively crosses a certain moral threshold of material consumption- and sensory gratification-related *pāpa* (bad karma, vice), making it necessary for the karmically driven divine retributive machinery to inflict another compassion-inspiring purgative natural calamity upon the community [CI/E]	In June alone: a considerable shift towards a wetter and significantly more extreme regional precipitation regime over the past century and particularly over the past half century; during the June-September summer monsoon season: some wetting of the regional climate with an increase in extreme precipitation over the past three decades, but no intensification of precipitation at all over the past century or the past half-century [PQDA: see Section 4.1.2.1.1]; regional climate projections indicating intensification of monsoon precipitation with sharp increases in extremes over the 21st century [PAW: see Appendix 4B.2], concomitant with annual mean temperature increases of around 2°C by the 2030s and >4°C by the 2080s under the RCP 8.5, SRES A1B and SRES A2 scenarios [PAW: see Appendix 4A.2] Implication: Amplification of the hazard through the heightened risk of precipitation-triggered flash flooding and landsliding operating in conjunction with thermally induced slope destabilisation in the glacierised and periglacial terrain immediately upstream of the Kédārnāth settlement [FO]	Increased monsoon precipitation intensity with a proliferation of short-spell, high-intensity rainfall events in recent decades despite a decline in total monsoon precipitation amount over the past half century; increased intensity and frequency of June thunderstorm precipitation over the past half century; the greatest increases in temperature as well as rainfall intensity being felt at the highest elevations [CI] Implication: Identical to that identified by Western science, except that interactions of extreme weather events with the geomorphology are karmically governed through the *jyotirlinga* (radiant cosmic phallic pillar) that is the holy essence of the towering Kédārnāth mountain [CI/E]	Several hundred casualties; complete or partial destruction (despite protection from the newly constructed flood defences) of about one-third of the main Kédārnāth settlement (including, in particular, about 40 buildings located close to the Sarasvatī stream and a crucial bridge), the helipad by the Sarasvatī channel immediately upstream of the main Kédārnāth settlement, and about three-fourths of the new pilgrims' camp and the attached helipad, which are located on a terrace off the left bank of the Mandākinī downstream of the main Kédārnāth settlement, directly below a Last Glacial moraine with extensive debris flow scarring from the June 2013 event [FO: see Figs. 4.32-4.34, 4.38; see also Fig 4.39 for the terrace locations (off the left bank) that can be expected to remain safe]	As an overwhelmingly powerful expression of geophysical energy (conceptualised in the Hindu religious context as a revelation of the *jyotirlinga*, a radiant cosmic phallic pillar associated with Lord Shiva, the embodiment of the Universe's destructive principle, who liberates the self from material existence), the hazard may present exposed individuals with a rare opportunity to gain deep emotional insight into nature and the human condition, which may eventually lead to a psychological state of complete invulnerability to every kind of physical hazard and suffering, representing *mukti* or liberation from the bondage of karma [CI/E]

Data sources are provided in parentheses. PAW: published academic work, FO: field (geomorphological) observations, PQDA: primary quantitative data analysis, CI: community interviews, E: ethnography

5.4. Towards a more efficacious epistemology of hazards

This chapter places ontologically disparate local/traditional and Western/modern scientific understandings of climate-related high-mountain geohazards into the context of each other, allowing the unique insights offered by each to be appreciated against the backdrop of the other. It uses shared geographies to integrate the two seemingly irreconcilable knowledge systems, both spatially – through geomorphological maps and sketches – and conceptually – through physical and metaphysical models of landscape processes.

The integrative project is undertaken in the pluralist spirit of "two-eyed seeing" (Bartlett, Marshall and Marshall 2007, 2012; see Section 2.1.2). This favours a mutually enriching co-existence of fundamentally different or even contradictory understandings over a contrived fusion or race-for-dominance between perspectives to arrive at a singular "correct" view (Ford et al. 2016, Martin 2012). The analysis finds, for example, that while Western geoscientific causation operates within the realm of physical reality, local/traditional *karma*-based ontologies of geohazards transcend material processes and use moral consciousness as the causal medium through which non-physical "impulses" travel from a physical cause to its physical effect. Despite appreciating this intrinsic incongruence between the two worldviews, the analysis positions them alongside each other, enabling the methodological rigour and precision of abstractively developed Western geoscience to complement the context-specificity and experiential groundedness of situationally developed local geographical knowledges. Western scientific and local knowledge-based hazard appraisals are systematically compared, but to initiate a collaborative epistemic dialogue rather than to pit quantitative geoscientific models of landscape dynamics against qualitative folkloristic models that lend geological form and spatiality to traditional metaphysical convictions, spiritualities, moralities, and emotionalities associated with geohazards operating within a certain social change context. This generates a rich, multi-dimensional understanding of geohazards, which is both scientifically well-founded and culturally situated.

Remarkably, Western science and local knowledges in both ULC and UM understand the *physicality* of high-mountain geomorphic processes in very similar ways. This causes them to make similar inferences about the magnitude of a given geohazard. Moreover, the nuanced ground-level observations of regional- and local-scale geomorphic peculiarities provided by local experiential knowledge usefully complement the quantitatively sophisticated simulation models of geohazards offered by Western science. Both knowledge systems also agree that a warming climate with increasingly more extreme summer precipitation and declining snowfall is exacerbating high-mountain geohazards such as glacial lake outburst floods and debris flows; they even make similar observations on the geohazard-amplifying effects of climatic change on geomorphic processes. This shows that the two knowledge systems may be able to work together towards risk assessment and management. However, traditional knowledges in both ULC and UM do still conceive of hazard-shaping and hazard-triggering geophysical processes (meteorological, climatic, geomorphic, and hydrologic) as mere physical expressions of an invisible anthropogenically influenced machinery that administers moral justice in accordance with the shared Hindu-Buddhist metaphysical doctrine of *karma*. This makes traditional knowledge-based appraisals of the likelihood of geohazard activation dependent on the physically indeterminable need for a morally purgative, spiritually revelatory catastrophe, and therefore incomparable with geoscientific risk assessments. Nonetheless, the karmic control over geophysical (including atmospheric) processes often makes traditional knowledge holders attribute a hydrometeorologically triggered disaster to cumulative human vice resulting from excessive collective material consumption. Despite its fundamentally different underlying causal mechanism, this *moral* explanation is functionally compatible with the *physical* understanding of Western science that anthropogenic greenhouse gas emissions caused by global-scale human consumption contribute to geohazard-activating hydrometeorological extremes. Therefore, Western scientific and local epistemologies of geohazards in the two study regions may not be entirely irreconcilable.

A key practical outcome of the chapter's epistemological pluralism is that it enriches earth science-based hazard assessments with ethnographically robust emic perspectives on geomorphic processes, providing external development practitioners, planners and policymakers with a genuine sense of lived experiences of change and extremes in the physical environment. Through its deep engagement with the neglected but behaviourally potent psycho-cultural and religio-spiritual dimensions of human-environment relationships, this chapter advances a holistic epistemology of climate-related geohazards. This can aid in developing more culturally compatible, and therefore potentially more efficacious, strategies for climate change adaptation and disaster risk reduction among remote, traditional high-mountain societies in the Global South. This purpose is pursued in Chapter 7, after Chapter 6 develops the implications of the current and the previous chapter for understanding adaptive capacity.

6. Appraising adaptive capacity

The previous chapter exhaustively examined the Upper Lāchen Chú (ULC) and the Upper Mandākinī (UM) communities' physical and metaphysical conceptions of the geophysical hazards present in their changing environments, as well as their exposure to those hazards in terms of the spatial relationships between habitation and geomorphology. The next step in developing a fuller, abundantly emic, and solution-oriented understanding of disaster risk is to cast light on local perspectives on the two communities' adaptive capacities in the face of those hazards. The reasons for framing the analytical discussion in this chapter in terms of adaptive capacity rather than vulnerability or resilience can be found in Section 2.2.2 (see also Cutter et al. 2008, Engle 2011).

Both communities express their constructions of adaptive capacity in three dimensions – the *tangible* and the *intangible* on the worldly plane (i.e. within the realm of sensory experience), and the *transcendental* in the mystical realm that is believed to exist beyond physicality and temporality. The worldly-tangible dimension embraces such material entities as bodies of living beings, buildings and physical infrastructure, while the worldly-intangible dimension represents all environmental, social, economic and political structures and processes as well as the entirety of a person's cognitive and emotional engagements with the material world. The transcendental dimension relates to a purportedly "liberated", materially unaffected consciousness that transcends the "illusion" of which physical reality is believed to be composed, bringing about a realisation of the Buddhist ideal of non-self or complete nothingness and the Hindu ideal of true self or the ultimate all-pervading reality that is infinite and eternal (equivalent to "God"). These dimensions are conceptually analogous to the triad of body, mind, and spirit.

Engaging ethnographically with the two communities' senses of the transcendental dimension as well as related elements of the worldly-intangible dimension of their own adaptive capacity, Section 6.1 attempts to exhume the deep and complex psycho-cultural foundations of the local metaphysics of disaster risk and the spiritualities, emotionalities, and moralities surrounding it. Although completely overlooked or significantly under-recognised in conventional assessments of vulnerability/resilience, these subtle psycho-cultural factors are behaviourally potent and underpin the socio-economic and governance-related dimensions of adaptive capacity (see, for example, Schipper et al. 2014, Schipper 2010, Bankoff 2004, Gaillard and Texier 2010). Therefore, the entire first half of this chapter is dedicated to them.

Moving on from deep philosophical narratives to relatively mundane socio-economic and logistical data obtained through fairly structured interviews, the contrastingly more objective and practically oriented Section 6.2 exposes individuals' purely worldly, operational understandings of their community's adaptive capacity in relation to climate-related geohazards. The governmental risk governance machinery is also appraised here as an element of community adaptive capacity that mostly lies beyond the community itself.

The empirical insights gained through this chapter feed into a summary review of both communities' adaptive capacities in Chapter 7, which uses a practice theory-based framework to unite the subtle psycho-cultural elements examined in Section 6.1 with the more tangible socio-economic and managerial elements detailed in Section 6.2. That review is used to devise a strategic framework for culturally sensitive action towards efficaciously supporting climate change adaptation and disaster risk reduction in remote, traditional high-mountain societies across the Global South.

6.1. Senses of adaptive capacity: Metaphysical insights

The ontological dualism that was seen in the communities' relationships with environmental hazards naturally extends to their understandings of their own adaptive capacity and their aspirations with regard to it. On the one hand is a worldview that transcends the "illusory" physicality of human existence, and on the other is a mundane sense of attachment to material possessions (including the body itself) as well as the fear of losing them. Although seemingly mutually antithetical, the two kinds of metaphysical engagement with human (in)vulnerability do go hand in hand within most interviewees' minds, generating among both communities varied sets of multi-layered conceptions of environmental risk. Using insights from both the ULC and the UM cultures, this section illustrates the above complexities and their implications for disaster risk reduction and climate change adaptation.

6.1.1. Insights from the Upper Lāchen Chú Valley

Some in the ULC community (5 of 30 interviewees) present a decidedly incorporeal worldview, which renders (material) vulnerability, and therefore risk (of material loss), redundant. These individuals express a deep, affectionate faith in the physical landscape, its agency, and its 'intent'; natural hazards seem to evoke little or no fear (even of death), panic or distress in them. They dismiss the fear of death with such philosophical statements as: *"Haha, death is the end of a great mystery – shouldn't you be looking forward to it?"* and "*Life is full of risks, and that is what makes it worth living; the biggest risk is that of death – but what is life without death?"* Moreover, they seem excited at the prospect of experiencing (i.e. witnessing and participating in) an overwhelmingly powerful release of geologically embodied divine wrathful energy. Grandpa Tāshī's words elucidate this sentiment:

> *"Don't you see how benevolent our mountains are? By the grace of the gods and the great Guru Rinpochë, they have given us all we have. They will never fail their own people, animals, trees... And if they do something terrible to us, there will be a good reason for that… The mountains have borne the weight of our wrongdoings for centuries… Their rocks, snows and waters have been absorbing all the bad karma [vicious deeds and their merited consequences], and that bad karma has been fuelling the wrath of the great deities that dwell inside them… There will come a time when all the wrath must erupt and reveal itself, and that revelation will cleanse us from all that ails us. At that moment, you and I will be breathing the same breath as the mountains, the rivers, and the great birds in flight… To live through the fury or be killed by it will be the ultimate experience, a great transformation, a glimpse of the 'truth'… Don't fear death; it is part of life - the gateway to the next life… or the gateway to* parinirvāna *[lit. 'the ultimate extinguishment'; perfect emptiness or nothingness following release from* samsāra*, the illusory world with its afflictive recursive loop of birth, growth, death and rebirth]!"*

Grandpa Tāshī's notion that the mountains "have borne the weight of our wrongdoings for centuries" reflects his cultural and spiritual association with the geophysical landscape as a medium for the administration of karmic justice and as an instrument of salvation. It indicates a perceived transformation of karmic energy into geophysical energy such that a materially catastrophic event such as a flash flood represents a morally purgative spiritual climax. This 'geo-cathartic' consciousness pervades a significant part of the community and seems embedded in the local culture as all 30 interviewees express intense emotional associations with the sacred mountain landscape even in casual conversations about everyday life, often effusing a faith in some manner of deep, dynamic unity between the psychological and the geological.

According to the Buddhist (and Hindu) view of reality, the material world is *māyā*, an illusory experience of phenomena that do not exist independently of one's consciousness of them. *Māyā* interferes with *prajñā-pāramitā* (lit. 'wisdom perfection') or the attainment of a perfectly clear transcendental understanding of reality, which is the primary mechanism for dispelling all *duhkha* (worldly pain, suffering, grief and unfulfilled-ness, ranging in emotional expression from an elusive sense of existential unease to cataclysmic anguish) and achieving the ultimate ontological goal of *nirvāna* (lit. 'extinguishment' of the 'three fires' of *rāga* or sensory attachment, *dvésha* or sensory aversion, and *moha* or delusion; perfect emptiness or nothingness following liberation from *samsāra*).

Episodes of acute, devastating *duhkha* are understood to have the potential to inspire deep awe and trigger spontaneous *māyā*-shattering "awakenings" marked by surges of overwhelming compassion even in the most materialistic of experiencers. When not regarded as psychotic and actively suppressed, such emotional arousals are believed to act as opportunities for necessary shifts of consciousness that transform the reality of one's existence. (Any interference with Nature to deprive fellow humans, yaks and other sentient beings of such redemptive opportunities is to be regarded as extremely uncompassionate and a crime against their consciousness.) Occasionally, a catastrophic event may spark mass eruptions of acute *duhkha* in a community. The genesis of such *duhkha* may even be geo-psycho-cultural, i.e. it may involve the release of geophysical energy and its destructive interaction with humans and other beings in a landscape that has certain culturally assigned metaphysical meanings. In such a situation, synchronous climactic emotional states in experiencers of the *duhkha* are believed to be capable of producing a powerful collective sense of bodily (material) oneness with the finite, evanescent earthly elements in action and a simultaneous self-annihilating realisation of incorporeal absorption into the infinite, timeless cosmos. This is expected to provide the experiencers with transcendental insight into *shūnyatā* (lit. zero-ness, devoid-ness, nothingness, hollowness) or *anātman,* the absolute absence and therefore the invulnerability of a self - a risk-extinguishing idea embodied by the legendary *vajra* (an indestructible 'thunderbolt' weapon made of a diamond-like substance), from which the locally practised Buddhist tradition of Vajrayāna derives its name.

The above metaphysical lens arguably allows at least some members of the community to rationalise natural disasters and indeed all kinds of intense suffering by gratefully accepting them as sacred gifts bestowed upon them by the cosmos. The sense of psychological invulnerability fostered by eco-metaphysical affirmations within the traditional Vajrayāna Buddhist cultural context is arguably a powerful adaptive force that challenges interventionist, materialist disaster risk reduction practices initiated by the rational, civilising modern state and its 'scientific' knowledge machinery. On a deeper, more systemic level, it projects metaphysical realisation, as opposed to economic growth or 'development', as the fundamental means and measure of human progress and well-being. Ultimately, a genuine acknowledgment and appreciation of traditional ontologies of the human-environment relationship can problematise the state's conventional, psycho-culturally disengaged approaches to geophysical risk and human welfare.

Distraught about "state-driven" modernist-materialist onslaughts on the mighty *vajra* weapon that symbolises traditional spiritual conviction, 4 of the 30 interviewees – all community elders – take solace in an abstraction from the Prajñā-pāramitā-hridaya (lit. 'wisdom perfection heart') or Heart Sūtra, an early medieval Buddhist text that describes how Avalokiteshvara, the compassion-embodying *bodhisattva* (enlightened being), meditated and perfected transcendental consciousness to attain liberation from the world and all its suffering: "*Gaté gaté pāragaté pārasamgaté bodhi svāhā!*" ("Gone, gone; gone across; gone completely beyond! An awakening! So it goes!"). This innate human capacity to make the ego "go away" and "awaken the consciousness from the slumber of worldly attachment", the elders argue, is the ultimate source of resilience – "of total invulnerability and invincibility".

Even though their deepest metaphysical convictions do seem to reflect the traditional religious emphasis on liberating the self from materiality, the vast majority of interviewees (21 of 30) exhibit a considerable degree of attachment to the material world and a clear indisposition towards death and material loss; they are eager to reduce risk by physically adapting to natural hazards. In fact, many of these individuals (10 of 21) regard the extensive local presence of the Army and the Indo-Tibetan Border Police (ITBP, a specialist high-mountain paramilitary force), both of which conducted successful rescue and relief operations in the aftermath of the 18 September 2011 earthquake, as a source of security and strength in the face of hazards. However, all 21 of them have fatalistic attitudes in that they assert that it is impossible to subdue Nature (i.e. mitigate natural hazards) and imprudent to attempt to do so, for example, by means of extensive engineering works. Consider, for instance, Pembā's submissiveness vis-à-vis the risks facing his community at Thánggū:

> *"I know that the river can swell up with mud and boulders and come into this kitchen, take our soup, and kill us. I know that the land under our feet and our yaks' and cows' feet can kill us. Earthquake, landslide, China [war or invasion]... anything can happen! Since the 2011 earthquake, I have had nightmares about being killed by the same landslide in different ways - it's an imaginary landslide, but it looks like those enormous ones across the river from the road above Thumbuk... But what can I do about it? I can only try to be a good man and pray for our well-being... If we are to be killed, clouds will burst and entire mountains will come down with this river and that river. Nothing will remain, only mud and boulders! These roads, bridges, houses and trucks are just toys - they will be wiped out! We can't overpower Nature; we shouldn't even try. If you think otherwise, just look at these mountains, this valley... Can any engineer in the world build something like this?"*

All 21 'worldly' interviewees also believe that surrendering to and contently embracing whatever life brings is the key to a peaceful and happy existence; a collective sense of humility towards Nature will keep the community from harm. As will also be seen in the UM valley, the community's traditional non-interventionist attitude often runs contrary to the developmental aspirations of the modern state and its rationalist, science-based mitigative engagement with environmental risk. This philosophical conflict was most recently witnessed in a 2016 experimental project that was celebrated as an innovation success story, especially outside the ULC region, after an external team of government scientists and other officials, engineers, and military and paramilitary personnel employed local porters and yaks to deploy a siphon pipeline system that partially drained the hazardous and rapidly expanding South Lhonák proglacial lake (Sharma et al. 2018; lake volume: ~6.6×10^7 m^3) in a nearby catchment, thereby significantly mitigating the hazard (etic perspective) but also generating fears about the lake's spirits having been angered (emic perspective) (see Ice Stupa Team, 2016).

If the state's decision-making process in the above disaster risk management situation gave any consideration to the "irrational" and "superstitious" traditional metaphysicalities represented by the "moods" of the lake's physically non-existent "spirits", it would be seen as absolutely inimical to modern scientific rationality and to efficiency in carrying out the basic task of protecting life and property. However, refusing to engage with the local metaphysics of risk and simply disregarding the possibility of finding adaptive (as opposed to mitigative) solutions that are culturally compatible would arguably amount to the unethical disenfranchisement and political marginalisation of the indigenous culture (see Comberti et al. 2016).

A workable solution to the above quandary may lie in a patient dialogue between modern materialist and traditional non-materialist knowledges and ideals, which this dissertation consistently endeavours to facilitate. Perhaps the neighbouring nation of Bhutan has some inspiration to offer in this regard. The Bhutanese state officially recognises Gross National Happiness (GNH) as an alternative to Gross National Income – a policy choice that seems to have arisen from the same traditional eco-metaphysical values as the ULC community's, but also the need to tangibly and practically harmonise them with modern ("Western") materialist values.

The GNH index gives equal importance to material and non-material aspects of human welfare and progress. Apart from living standards (indicated by income, wealth, financial security, and access to housing, electricity and improved water sources), the index uses eight other domains to assess a person's state of being as unhappy, narrowly happy, extensively happy, or deeply happy: (i) health (including mental health and disability), (ii) education (not only literacy and formal educational attainment, but all kinds of knowledge (including cultural and ecological), vocational skills, and values), (iii) good governance (including political participation, perceptions of government performance, and access to civil and political rights and freedoms), (iv) ecological diversity and resilience (including environmental awareness and beliefs, social-ecological relationships, energy use, and waste generation), (v) time use (proportions spent on work, non-work activities, and sleep), (vi) psychological well-being (including life satisfaction and spirituality), (vii) cultural diversity and resilience (including engagement with traditional linguistic, folkloristic, moral, and metaphysical heritage), and (viii) community vitality (including relationships and senses of belonging within families and communities, social cohesion, trust and safety, and volunteerism) (Centre for Bhutan Studies and GNH Research 2016). This metaphysically syncretic, balanced and holistic framework for appraising and enhancing human well-being also seems specifically useful in the development of psycho-culturally sensitive approaches to traditional communities' adaptive capacities in the context of rapid and hazardous environmental change.

6.1.2. Insights from the Upper Mandākinī Valley

Akin to what was witnessed in the ULC community, a small proportion of UM interviewees (3 of 30) have cultivated a purely spiritualistic understanding of the world, which induces them to completely disregard material vulnerability (and therefore risk) as *māyā moha* (illusory deception). These individuals are only interested in an adaptive capacity that brings about and sustains an ontologically transformative realisation of their own indomitability and indestructibility; they completely disregard the tangible, material dimension of adaptive capacity, but occasionally retain a peripheral interest in such intangible aspects of worldly consciousness as emotional strength and moral fortitude, which are often relevant to metaphysical quests. Also, they do not express any fear of death; although they do not exhibit any suicidal tendencies either, they seem to celebrate and look forward to death and even near-death experiences as opportunities for *mukti (moksha)* or the ultimate spiritual goal of liberation by self-realisation.

The practitioners of "unworldliness" described above are all Hindu priests influenced by the revered 8th-century metaphysician Ādi Shankara, who is believed to have died in Kédārnāth. Their philosophy, as well as a significant part of the wider traditional metaphysical belief system of their community, is rooted in the non-dualist Advaita Védānta school of Hindu thought, which regards *ātman* (the transcendental essence of an individual's being; the 'soul' or true inner self; or the pure, materially uncontaminated consciousness) as identical to *brahman* (the immanent, ultimate reality that is *akāla* or time/space-less and *anādi-ananta* or without beginning or end; the fundamental cosmic principle; or the absolute – a construct that corresponds to the dominant view of 'God' across most schools of thought within Hinduism; cf. Carl Jung's *kollektives Unbewusstes* or 'collective unconscious': see Jung 1955, 1969). *Mukti*, therefore, comes when *brahman* is realised within oneself; it liberates the being from *samsāra*, the illusory world with its afflictive material cycles such as that of birth and death. *Brahman* is said to come alive in the figurative cosmic dance of *Shiva*, who is materially represented at Kédārnāth as a *jyotirlinga* (radiant *linga* or phallic pillar in union with a *yonī* or vulvular pedestal that symbolises *Shakti* or cosmic energy).

Simultaneously hyperventilating, wailing, laughing and shaking his head to work himself up into a mystical frenzy while playing his small *damaru* (double-headed hand drum associated with Shiva's dance), Rājéshwar whispers forcefully into my ears:

> *"After seventy years of service, I have earned one revelation from the Master: Worldly existence itself is a hazard, a disease… If you must be scared, fear having to come back to the unreality of this world to live another life! And what story are you scribbling?* He *is the one who writes all stories! Remember: Your body and mind are just puppets - they will always dance to* His *tune! If this mountain falls, you will run, run, run… till you are under the mountain. That's all you can do… Hahaha! Hahaha! Then you will leave this body and your loved ones will grieve the illusion that is your death. But how can that which was never born ever die?* "Chidānandarūpah shivoham shivoham*!" [in Sanskrit, from Ādi Shankara's* Nirvānashatakam*, lit. 'six verses to salvation']: "I am Shiva [lit. 'the ultimate auspiciousness'], I am Shiva, the pure, eternal, ever-blissful consciousness!" Haha!"*

Pūran, a relatively composed but teary-eyed middle-aged practising priest who describes his personal *mārga* or path to salvation (read: invulnerability) as that of *bhakti* or unconditional love rather than that of *jñāna* or transcendental knowledge, offers me some more personal advice:

> *"When the sole object… of all your worldly actions is to unite with the divine, there can never be any fear. There is an old folk song I heard at the feet of Gangā Maiyā [Mother Ganges] in Banāras [Vārānasī, a Hindu sacred site on the plains] many years ago:* "Morā saiyāñ bulāvé ādhī rāt / Nadiyā bairī bhayī": *"My beloved calls me at midnight / The river is raging high". The beloved, of course, is God, and the dark, raging river is this world. The river is determined to sweep you away, but if you are a true* prémī *[lover], you will somehow get to the other side... When I was caught in the flood and this life was slipping out of this body, my mind had no fear… The union was not meant to happen then, so here I am…"*

A large crowd of pilgrims returns to the temple for the evening prayer, chanting, "Hara Hara Mahādéva *[Sweep away, sweep away, O Great Lord]!*" (What is to be swept away here is actually the worldly ego, without which there is no sense of vulnerability or fear.) In the same spirit, a very frail, aged pilgrim raises her arms and cries, *"Lift me, O Lord! Lift me up now!"* She reminds me of the words of Damayantī, a middle-aged widow in a nearby village:

> *"Take me into your arms, O Lord! If you can't come down, let me come up… We are fools. We are intoxicated. We are trapped in* māyā-jāl *[the web of illusion]…"*

The spiritual endeavour that all of the above statements reflect is to shatter the constrictive, vulnerability-inducing ego and attain a liberated, all-embracing state of existence that remains untouched by the vicissitudes of mundane materialities. The sentiments expressed here about liberation from a world of illusion have the same philosophical roots, foster the same kind of psychological immunity in the face of material risk, and are expressed with the same emotional intensity as what I referred to as a sense of 'geo-catharsis' in the Buddhist ULC community. There is only one theoretical difference between the outlooks of the two communities: In philosophical history, the Buddhist ontological principle of soul-negation, which is prevalent in the ULC community, marks a reactionary departure from the older Hindu soul-affirming metaphysicality, which is deeply embedded in the psyche of the UM community. These contrasting perspectives generate disparate understandings of the dynamics of *samsāra*, a conception of the world shared by the two philosophies: Whereas the UM community views rebirth both as a means of karmic perpetuation and as transmigration of the soul, the ULC community generally believes only in karmic processual continuity from one life to the next without any eternal essence leaving one corporeal entity to enter another. For the soul-affirming UM community, liberation from *samsāra* and karmic bondage comes through the realisation of *ātman* (the true individual self) as *brahman* (the ultimate, timeless and all-pervading reality) – a construct expressed variously by local priests as "I am all that there is!", "I am the eternal truth!", "I am the essence of the entire cosmos!", etc.; for the soul-negating ULC community, it comes through the realisation of *anātman* (lit. 'non-self') or complete nothingness – an idea expressed by some local monks as "I am not!" or "The illusion that I was has been extinguished!". Nonetheless, the ultimate personal goal in both religious traditions is essentially the psychological obliteration of worldly vulnerability.

Rooted in the mass religiosity of the largely Brahmin (priestly-caste) UM community, anti-materialist worldviews and associated values and moralities spread far beyond the sub-cultures of élite practising priests *(purohit)* and ascetics and mystics *(sādhu, bābā)*; they are regularly invoked by all interviewees, even those who are otherwise openly in pursuit of materiality and do not directly express any lofty otherworldly aspirations. For example, Āshā, a worldly housewife and farmer in her forties who wants to "live to see the day" when her children shall have *naukar-chākar* (lit. 'servants and suchlike'; wealth and its socio-political affordances), also firmly believes in the Hindu (and Buddhist) ideal of non-attachment to the material world:

> *"You have to understand that desire is the cause of suffering. I have a relative who wanted to make lots of money and buy fancy clothes and cars… to woo* dhīlī-dhālī *[lit. 'loose'; frivolous, feckless] women. He couldn't control that desire… He had a lodge close to the river. His father had built it. He thought it was too small and modest, so he added a couple of storeys to it. The Lord's river swelled and took the whole thing away… That chap came to me and cried for two hours. I advised him to purify himself, his thoughts, his deeds. "Work hard," I said to him, "and never get attached to the fruits of your labour… Those fruits belong to the Lord, your maker." My advice will come to his rescue next time…"*

Notwithstanding the community-wide ideological and aspirational dissonance represented by Āshā's internally inconsistent view of worldly existence, the vast majority of interviewees (27 of 30) do express a host of concerns and anxieties about everyday life and exhibit a considerable degree of attachment to the material world. This points to the functional absence of a spiritually induced sense of invincibility or immortality in the face of environmental hazards (and, equally, the presence of a potent sense of vulnerability) among most members of the community. Nonetheless, all of these individuals express clearly fatalistic attitudes; despite a significant fear of death and material loss, they are inclined to succumb to or embrace hazards as part and parcel of a divinely or cosmically ordained karmic fate. Consider, for example, young Bidyā's thoughts about previous disasters:

> "*Remember Lord Shiva's* tāndava *[furious dance] in Kédārnāth? Danger, danger… so much danger… in the rainy season... but all is in God's hands… My husband remained in the forest for six days without food or water… When he came back home, he was all… empty stomach, dry mouth, trembling feet… His condition was awful… But he was intact… By the Lord's grace, he returned safe and sound… No harm was done. Even the mules came back in three or four months… But my friend's very nice husband never came back – that was their fate… These things are divinely ordained according to your karma from this life and previous ones. So just be good and keep praying… Big landslides have happened in my parents' village near Ukhīmath… One happened when I was little. Another happened after I got married… The losses were immense. Many people died, homes were washed away… It was heartbreaking... There was too much damage. Crops were destroyed. Well, all is God's grace… If he wants, he can make it rain right now… If he wants, he can make the sun shine… We can't tell anything… Before the face of God, who can… We are helpless… Just recently, there was a cloudburst… Karnprayāg or Nand… where did it burst? So many casualties! All this keeps on happening…"*

The vast majority even of those interviewees who claim to practise *duniyādārī* or worldliness (85% of 27) perceive natural hazards as geological manifestations of Lord Shiva's *rudra*[5] (wrathful) form; in fact, some even express a sense of reverential gratitude towards the 2013 disaster, believing that the sufferings inflicted by it fostered moral fortitude and at least temporarily arrested the male lust-driven, eco-spiritually unsustainable growth of *adharma*. For instance, Kamalā, a farmer in her sixties, remarks:

> *"Pious people, especially pious men, are nowhere to be found. That is why there is a disaster every year… How else will* pāpa *[bad karma] be extinguished? How else will the right path be shown? Only the Lord's* rudra *powers can instil discipline in us... When his wrath comes out of the sky and earth, it is a great blessing, a source of strength for the spirit.* Hara Hara Mahādéva! *[Sweep away, sweep away, O Great Lord!]"*

Hariyālī, a young mother, holds a similar view:

> "*Each time the mountains fall, it is a scolding from Mother Earth... We must listen to it quietly because it is for our own good… If the mother is not strict, how will her children be good?"*

Durgā, a middle-aged housewife who loves everything about television "except that they show too many vamps instead of wayward men", emphasises the importance of moral-emotional and spiritual resilience in the face of disaster, which, she also believes, is an essential element of her cultural identity as a "materialistically unsullied" rustic highlander and especially as a woman in a "pure, pious priestly household":

> *"If you want to live here, you have to live with disasters… A disaster can kill you, but it can also make you a better person, a stronger person. If you can't live with these hazards, go down to the plains… Go, go, rot there… Go down! Leave the mountains! Leave us alone… Many of our young men are faint-hearted, morally weak, even depraved… They should go down and live in a city – eat money, drink money, vomit money… Hehe… I'm happy here… with my Lord."*

These worldly-but-fatalistic individuals may be willing to adapt to geophysical hazards, but most of them (22 of 27) believe that it is impossible, futile, unnecessary, or/and immoral to mitigate or challenge them. Only one-tenth of all interviewees (3 of 30) express positive expectations about structural hazard mitigation and redevelopment; more than one-third (12 of 30) raise objections to the ongoing government-commanded rebuilding and expansion of the Kédārnāth settlement (driven primarily by the establishment's ambition to boost pilgrim numbers and associated economic gains) and also to engineering-based hazard mitigation interventions such as the (now-finished) construction of a gabion wall upstream of the settlement.

Kamal and Chhatrapāl, both young, nimble-bodied immigrant manual workers from Népāl, question the value of their own rebuilding work, making the broader argument that vulnerability arises from the very act of possession, so development, which essentially entails the growth of material possessions, only increases

---

[5] *Rudra*-prayāg (lit. 'fierce confluence' of sacred rivers that symbolise cosmic energies) is the town where the Mandākinī River (which comes from Kédārnāth, the geological embodiment of Shiva, the Universe's destructive principle, which liberates the self from material existence) joins the larger Alakanandā River (which comes from Badrināth, the geological embodiment of Vishnu, the Universe's sustaining principle, which binds the self to material existence); since the district-level government is headquartered in that town, the district itself is known as Rudraprayāg.

vulnerability in face of environmental hazards. They go on to label the state-led reconstruction project as an imprudent, egotistically driven attempt at competing with and subjugating the indomitable power of Nature.

> *"Before, there was nothing here, only ruins. Then we brought a vehicle, the JCB stuff, huge guarders… built the helipads and a new bridge at the confluence… Now we're building the* ghāt *[access stairs for holy dips in the river]… But when the next disaster happens, there will be so much more destruction… The more you have, the more you fear… If you have nothing, you have nothing to lose… Those who are making us build all this don't realise that it doesn't have to be like this – that we don't have to compete with Nature. They want to defeat Nature, but aren't they part of it themselves? They say, "We undid the disaster!" But the disaster was God's doing… Nobody can undo it. Instead of learning a lesson from Nature, they want to teach Nature a lesson… But Nature is God..."*

Their Garhwālī colleague Bīréndra concurs:

> *"Haha, we have built again and He will destroy again… There is no way anybody can prevent another disaster. All this construction will lead to an even bigger disaster. … This is being done so that more and more pilgrims can come… It's already a Kumbha Mélā [grand fair] out there… Too many people, too many mules, too many helicopters, too much garbage… If 2,000 died last time, 4,000 will die the next time there is a flood…"*

The schoolteacher Ravi warns me:

> *"Too many people had started to come to Kédārnāth, and there was too much construction – more than the land could take… That's why it was all wiped out in 2013… And now they are making the mistake of building even more than there was before the disaster… Surely the Earth will penalise us…"*

Pushpésh, a young lodge helper, has separate but linked practical and spiritual concerns about the ongoing reconstruction – that its design in relation to environmental hazards is thoroughly maladaptive and that it is inherently a threat to the sacred, awe-inspiring character of the relatively pristine landscape:

> *"They've built the filthy new camp for pilgrims just below those huge scars from the 2013 disaster… and they say that the old town is unsafe! They are just stupid! And those fancy fences and walls they've built behind the holy temple… I mean… there's a whole sea of mighty boulders behind them! God knows how much money the rogues have spent on it... Very soon, Kédārnāth will become a noisy, ugly, smutty town… like Rudraprayāg; its bond with the Lord will be broken… forever."*

Not surprisingly, field evidence from similar Himalayan settings with traditional societies indicates that when a construction project undertaken by an external engineering agency fails due to imprudent siting or positioning in relation to the spatial configurations of geohazards such as potential debris flows, it is often because the project was initiated without any geo-safety consultations with local residents (see Kaul 2012, pp. 39, 90; Kaul and Thornton 2014), whose advice on siting or design might be based on centuries-long accumulations of local environmental experience that are encoded within geographically referenced religio-metaphysical folklore (see Chapter 5).

The priest Umāpati, who claims to "know every spur and gully in this most divine landscape like my fingers and toes", also sounds gravely concerned about the magnitude of the ongoing interference with the physical environment:

> “*We’d better not mess around with the Himālaya… like… up there, where the glacier comes down onto the holy site of the all-powerful* jyotirlinga*… there are machines there, constructing huge walls… JCBs everywhere… This place looks like an industrial site… The government is indeed bringing about development, but development shouldn’t be of the kind that leads to another disaster and brings us back to square one.”*

The above assertions relate fundamentally to sustainability and comprise both philosophical elements (e.g. theological or karmic determinism, moral environmentalism and anti-developmentalism) and practical considerations (e.g. concerns about heightening exposure to hazards and exceeding the “carrying capacity” of the landscape); they are driven by a convergence of spiritual and ecological convictions that leads members of the community to challenge the modernist state’s environmentally “irresponsible”, culturally “belligerent”, and purportedly vulnerability-amplifying approach to post-disaster rebuilding in particular and development in general. This reflects a deeper societal aspiration, fuelled by the resurgence of traditional eco-spiritualist values following the 2013 disaster – to thoroughly interrogate the structural forces of capitalist development that engender modernisation. In fact, it ultimately raises the profound question of whether materialist modernity itself is the fundamental source of vulnerability in the face of environmental extremes.

Much like the ULC community, the UM community points to the critical role that traditional eco-metaphysical convictions tend to play in local constructions of (in)vulnerability vis-à-vis climate-related geophysical hazards. Unless the deep psycho-cultural roots of local environmental knowledges are exposed and appreciated, it may not be possible to develop a truly emic perspective on human-environment relationships, especially in the context of remote traditional communities that are faced with rapid socio-environmental change.

Since there is not a single interviewee (in either community) who does not have a sense of metaphysical inquiry and mystical ambition, the above discussion of the generally neglected psycho-cultural dimension of adaptive capacity forms a critical empirical base on which to build a socially appropriate adaptive strategy. However, the everyday, worldly aspects of adaptive capacity are certainly no less vital to the communities, and indeed to their livelihoods, than moral-spiritual fortitude. The next logical step towards building a holistic empirical platform for environmental risk management, therefore, is to explicitly appraise the communities’ practical and operational readiness and capacities for response and recovery in the face of *material* risk. The following section examines, largely through an emic lens, what already makes the communities resilient in terms of their social, economic, logistical, and governancial resources, and also briefly considers what the communities themselves think might enhance their existing adaptive capacities in the context of livelihoods.

6.2. Worldly adaptive capacity: Practical appraisals

Moving on from metaphysicalities, moral-spiritual realities and ethereal emotionalities to everyday practicalities, this section explores the entirely worldly socio-economic and managerial dimensions of the ULC and UM communities' appraisals of their own adaptive capacities in relation to climate-related geophysical hazards. It does so with a view to taking stock of the resources that are and are not already available to the communities vis-à-vis their ability to socio-economically adapt to a more extreme environment. The extensive inventorying exercise that follows is certainly more prosaic than the ethnographic psycho-cultural exploration undertaken in the previous section. Nonetheless, it is fundamental to the development of a comprehensive, practically oriented adaptive strategy that successfully safeguards and improves lives and livelihoods.

6.2.1. Social factors

Literature from across the world, both on climate change adaptation and on disaster reduction and recovery, finds a very robust positive relationship between social capital and community resilience (see, for example, Adger 2003, Aldrich and Meyer 2014, Chamlee-Wright and Storr 2011, Murphy 2007, Nakagawa and Shaw 2004, Pelling and High 2005). The stronger the interpersonal relationships, shared identities and aspirations, and levels of trust and cooperation within a community, the better equipped it tends to be for both immediate response and long-term economic recovery, adaptation and transformation in the wake of an extreme environmental event. Both the ULC and the UM communities confirm this relationship in their narratives of the role of socialities and social structures in building resilience and augmenting adaptive capacity. The relatively multi-ethnic UM community also provides some insight into the socially differentiated nature of access to the resources that underpin its own adaptive capacity (see Thomas et al. 2019).

6.2.1.1. Upper Lāchen Chú Valley

The ULC community is largely ethnically homogeneous (Buddhist Bhutiā-Dokpā) and exhibits and self-reports very firm kinship bonds as well as pervasive, deep-seated senses of compassion, nobility, egality, and trust. This, along with its cooperative and organisational ability (previously demonstrated, for example, through a community-led anti-littering campaign directed at tourists, which achieved a local ban on plastic bottles in 2012) and a democratically elected, socially well-regarded and legally potent traditional village council known as the *dzumsá* (see Ingty 2017), seems to contribute significantly to the community's social resilience in terms of its collective capacity for efficacious disaster response and recovery. In addition, the community's spirituality and shared faith in Nature's 'intent' may strengthen resilience psycho-culturally, even though this may in fact foster intransigence and interfere with more interventionist and transformative resilience building practices such as engineering-based protection against hazards.

Dolmā, a housewife in her sixties, remarks in a buoyant voice:

> *"We are strong because we are good people and we live for one another. I am proud of our Lāchenpā community, our Dokpā sisters, our first-rate* dzumsá*. We have faith in our people, our mountains, this river… Nature will never do us wrong, and if it gives us a difficult time, it will be to make us hardier. There is great strength in submission – take my word for it… What has to come* will *come. I never feel helpless because I know that Guru Rinpochë is guiding us."*

Young Phuntsok elaborates on the community's shared sense of purpose and capacity to effect positive change through coordinated action:

> *"We are united. We cooperate with one another and can easily organise ourselves into a strong team for any good cause… In 2004, we set up the Lāchen Tourism Development Committee, which now has 33 local members. With the help of the WWF and the district administration, we brought in a ban on plastic bottles. To make the ban a success, we organised anti-littering awareness camps for taxi drivers and travel agents who bring city tourists into our valley. We even got the government to test our local water and certify that it was as at least as safe for drinking as bottled water. We also raised awareness about waste segregation and reuse within our community. We are working with the WWF to make saleable artefacts out of non-biodegradable waste."*

In the absence of much ethnic diversity or significant perceived socio-economic disparities, the ULC community's cohesiveness remains largely unchallenged. Although five of the dozens of male ethnic lowlander (mostly Bihārī) road construction workers working at different locations in the ULC valley were also interviewed (in addition to the main sample of 30), they identified themselves only as visitors (rather than members of the community as immigrants) who would leave the valley within the following half year, and who anyway had little to do with the "generally courteous and helpful" resident community. The everyday lives of the hundreds of Army and ITBP (paramilitary) personnel deployed in the ULC valley also generally do not spill out of their own separate, self-sustained settlements and operational spaces. They maintain pleasant but fairly formal relations with the "community", providing it with material and logistical assistance when necessary.

6.2.1.2. Upper Mandākinī Valley

The vast majority of UM interviewees (28 of 30) report strong resilience-fostering kinship bonds and high levels of cooperativeness within the "native", almost entirely Brahmin ethnic Garhwālī society. The priest Dinésh explains:

> *"Ours is a cohesive community… the priestly society… Not just now; it's been so for generations… We have the same clan goddess, Durgā Dévī… That's how we are all united. The goddess resides mainly in Phémū, and it was from there that our people emigrated… and then our villages came into being. Even in Kédārnāth, our lands are ancestral…"*

However, all immigrant working-class ("mid-caste" high-mountain Népālī and "low-caste" ethnic lowlander, especially Bihārī) interviewees (7 of 7) and nearly half of all Garhwālī interviewees (11 of 23) feel that differences in class, caste and perceived moral codes have prevented the various resident groups from operating as a single community. There is, in fact, a marked sense of differential adaptive capacities in the accounts of immigrant workers, who constitute a marginal group in that they tend to have the lowest incomes, the poorest access to social capital, and the greatest physical exposure to geohazards (see also Kaul and Thornton 2014). Nabīn, a shy man in his twenties, shares some of his experiences:

> *"Many old priests and even big-city pilgrims are mean just because I am Népālī. They treat me like a mule. Like… if there is somebody on my back… in a basket… and I want to take a pee-and-tea break… they just refuse to get off my back… I can't be rude to such people… If I say something to them, they might say something horrible to the police… Many people think we are thieves… We are poor and young… If we see money somewhere, we will pick it up… We may not be totally honest, but we're not thieves… If there is a disaster, we might be the first ones to die, apart from pilgrims in lodges that are too close to the river… We live in the worst buildings… We are near streams and on the riverbed all the time… with mules… We are only as safe as the mules… Many of our Népālī brothers and also some plains labourers live in makeshift shelters, tents…"*

Remarkably, more than half of all Garhwālī interviewees (14 of 23) regard the 2013 disaster as a socio-cultural watershed in that the extreme hardship and trauma have purportedly improved overall socio-emotional health and inter-ethnic relations. The tragedy, they believe, has inspired exceptional levels of compassion and generosity, fostered courage and solidarity through shared meaning-making around loss and a collective 'coming to terms' with it (for empirical work on positive psychosocial change following adversity and trauma, see, for example, Garrison and Sasser 2009, Janoff-Bulman and McPherson Frantz 1997, Linley and Joseph 2005, Tedeschi and Calhoun 1996). These interviewees also feel that the disaster has helped build greater community cohesion by weakening Brahminical isolationist attitudes and condescending casteist behaviour (especially towards sweeping staff and occasional pilgrims from the oppressed hereditary castes, whose members are traditionally regarded as *advija*, lit. 'non-twice-born', or spiritually uninitiated).

The priest Umāpati remarks:

> *"Before the disaster, people used to stay aloof. But since the disaster, everybody has really come together… Before, our community was beginning to disintegrate… Every individual was taking his own flight… But when the disaster happened, when the hour of grief came, people started to meet and greet one another, help one another… I feel that if something like that disaster happens again, people will be ready to stand by one another."*

His friend Dinésh adds*:*

> *"The thing is that the day the disaster happened, nobody was a Garhwālī, or a Népālī, or a pilgrim… There was no* ũñch-nīch *[distinction or discrimination, lit. 'high-low'], only humanity… In my own house, 300 or 350 people took shelter and ate together… That was the power of the disaster… It brought us all under one roof as one family."*

Considering the empirically supported positive relationship between rural community cohesion and resilience (Townshend et al. 2015, Ludin et al. 2018), the above narrative seems to suggest that the disaster has had a positive impact on the social dimension of adaptive capacity within the UM community. However, most immigrant working-class non-Garhwālīs (5 of 7) do not concur; in fact, they claim that displays of ethnicity-related bigotry by both Garhwālī community members and village-level authorities have seen an upsurge, owing to an increase in ritualistic religiosity and caste-based superstition since a few months after the 2013 disaster, when the intensity of the devastation "suddenly sank into people's minds and hit them very hard".

One middle-aged Népālī muleteer complains:

> *"Since the summer after the disaster, some locals have developed a* vehem *[superstitious fear] about us… They think we are vile, dishonest, promiscuous… that our* pāpa *[bad* karma*] is the cause of their misfortunes. There is… like… a rift between us and them."*

The dissonance between the two narratives of the impact of the disaster on inter-ethnic relations bears a similarity to the aftermath of the 2009 earthquake in Padang, Indonesia, where the ethnic Chinese minority widely alleged to have been discriminated against during the relief and recovery process, while the majority Pribumi ("native" Indonesian) ethnic group and local authorities tended to deny that allegation (Alfirdaus 2014). Moreover, the above situation seems to be in line with empirical evidence of perceived community cohesion growing in the aftermath of natural disasters, but also of the perceived improvement in community cohesion varying as a function of disaster severity such that cohesion increases between low and medium levels of disaster severity, but starts to decrease from medium towards high levels of disaster severity, owing to a shift of focus from cooperative behaviour intended for collective survival to competitive behaviour intended for individual security in the face of resource scarcity (Chang 2010, Calo-Blanco 2018).

Another social aspect of the UM community's adaptive capacity is its faith-based capital. The majority of Garhwālī interviewees (15 of 23) identify traditional religious patronage bonds as a major social support system for local priestly families; this refers to centuries- or decades-old, multi-generational deferential relationships between clans of ritual patrons or *yajamāna* from different parts of South Asia and the heads of the local *purohit* (priestly) families to which they have been ethnogeographically allocated. The generous outpouring of financial aid from wealthy urban *yajamāna* families in the aftermath of the 2013 disaster has reinforced faith in this system.

The priest (and proud patriarch) Umāpati recalls:

> "*Oh, what horrors we had to go through in 2013… We had nothing to eat… Everything had been shattered… but then and even after 2013, our patrons from all over India supported us to such an extent… perhaps we didn't even deserve all that they did for us… They didn't let us down at all… These lodges here are our patrons', not ours. They are determined to build them again… They arranged our children's fees, provided us with food and clothes… Since our patrons have stood by us so firmly, I urge our sons and grandsons to always honour this great religious tradition, this legacy… Today, we are alive only because of our patrons and their devotion to the Lord…"*

Most female interviewees (9 of 13) note, albeit nonchalantly, that the women of the priestly household have no administrative rights over *yajamāna* aid because it is awarded by male patrons to male priests; also, widows and dependent children of deceased male priests rarely receive *yajamāna* aid. Nonetheless, all of the 13 female interviewees believe that despite its parochial, gendered character, the community's religious set-up is a major contributor to its adaptive capacity, not only psychologically but also materially. Community-level disaster recovery has, in fact, been materially aided by 21st-century religious infrastructures across cultures, from churches in southwestern USA after the 2005 Hurricane Katrina disaster (Cain and Barthelemy 2008, Chamlee-Wright and Storr 2009, Rivera and Nickels 2014) to mosques in Indonesia after the 2006 Yogakarta earthquake disaster (Joakim and White 2015).

Nearly all interviewees (28 of 30) also point out that it was largely due to the religious significance of Kédārnāth that the June 2013 disaster attracted tremendous media attention and political engagement, which caused all levels of government, including the Prime Minister himself, to be "rather enthusiastic" about rebuilding and economic recovery. About half of all interviewees (14 of 30, including 11 of 17 males) identify Hindu nationalism, which the regime of the day promotes, as a major factor in the priestly UM community's relatively robust economic recovery, including the sharp rise in pilgrim numbers from about 40,000 in 2014 (a year after the disaster) to well over 300,000 in 2016 and over 730,000 in 2018, the highest in history (Shri Badrinath – Shri Kedarnath Temples Committee records).

Overall, both the UM and the ULC communities seem traditionally resilient in terms of their social and religio-spiritual capital. High levels of cohesiveness and cooperativeness contribute significantly to both communities' capacities for adaptive response and recovery in the face of geohazards. However, adaptive capacity tends to be socio-economically differentiated in the UM community, where non-priestly-caste immigrant manual workers from non-native ethnic groups tend to be more exposed to geohazards than the rest of the community, while also holding smaller adaptive capacities in terms of social support and economic assets. Besides, owing to gendered social roles, the vast majority of females in both communities tend to be financially dependent on male breadwinners, thereby being more socio-economically vulnerable and possessing smaller adaptive capacities than males. Men, however, have greater levels of exposure to geohazards due to their more outdoor-based occupations, especially in the UM community, where it is generally only men who seasonally leave their villages to seek commercial opportunities and employment at geophysically hazardous locations on the pilgrimage circuit.

6.2.2. Economic factors

The social dimension of both communities' adaptive capacities is inseparable from the economic infrastructure and assets upon which individuals and their social structures subsist. The discussion below presents both communities' appraisals of the critical economic resources that already are or are not yet available to them and can be combined with their own livelihood aspirations to fashion more resilient futures.

6.2.2.1. Appraisals of the current situation

The vast majority of interviewees in both communities (25 of 30 in ULC, 29 of 30 in UM) regard economic security as a key dimension of adaptive capacity in the face of environmental risk. This understanding comes with the acknowledgement that while material abundance may provide something to fall back on in the wake of sudden losses of livelihood resources, the more a family materially possesses at locations that are exposed to hazards, the more it risks losing (i.e. the greater is its vulnerability). The natural approach to economic resilience-building, therefore, has been to invest in resources that are physically far removed from the hazardous yet beloved and unabandonable highland home, which some in the UM community liken to a prickly floral bush, the nectar of whose flowers must be drunk by the bird despite all the thorns that are in its way.

In accordance with the above strategy, most interviewees are part of households that have savings accounts with post offices or banks (25 of 30 in ULC; 24 of 30 in UM); holdings of gold, silver, other precious metals, or traditional precious gemstones that are stored at the safest available locations within the village or with relatives outside the village (28 of 30 in ULC, 19 of 30 in UM); and immovable assets (14 of 19 in ULC – pertains to Thánggū-Lhāshar only; 20 of 30 in UM) and non-agricultural employment (19 of 30 in ULC; 26 of 30 in UM) outside the village. Most male interviewees aged 18-35 years (5 of 8 in ULC, all 7 of 7 in UM), but no females, from both communities say that they have been under significant pressure, both directly from their parents and indirectly from their more successful "*Rājū-ban-gayā-gentleman*" ("bumpkin-turned-urbanite") peers, to escape the discomforts and hardships of village life and chase the urban "dream". All interviewees in both the ULC and the UM communities explicitly (and without prompts) identify out-migration for employment as the most effective (although not the most favoured) means to enhance their adaptive capacity in the face of environmental extremes.

An extensive government survey (Rural Development and Migration Commission 2018) finds that 734 of the 15,745 (about 5%) villages in the UM community's Uttarakhand state were completely depopulated in the period 2011-2017; of these, 90% did not have a primary health centre, 66% were not connected to the road network, 54% did not have access to drinking water within a kilometre, and 49% did not have access to electricity. Likewise, another 565 villages in the state saw population declines of 50% or more in the same period. Within the district of Rudraprayāg, where the UM community is located, 20 villages were abandoned and another 23 lost half or more of their population during 2011-2017. Of these 43 villages, 36 had no basic healthcare facility, 32 were without road connectivity, 13 lacked access to drinking water within a kilometre, and 10 had not been electrified.

The above report identifies the main reasons for out-migration from villages in the Rudraprayāg district as poor employment/livelihood opportunities (53% of all cases), poor access to education (16%), poor access to healthcare (9%), wild animals intruding upon farmland (5%), lack of infrastructure (4%), and declining land productivity (4%). To what extent hydrometeorological extremes and related geohazards are directly or indirectly contributing to out-migration in the region remains statistically unknown; however, the vast majority of UM interviewees (24 of 30) regard the implications of geohazards for the security of lives and livelihoods as a key factor in post-2013 disaster decisions on whether to leave the village for good. All 30 UM interviewees also regard the adverse impact of chronic landslides on road connectivity, especially during the increasingly extreme summer monsoon season, as a critical threat to rural livelihoods and therefore a trigger for out-migration (which may be viewed as an adaptive response). This sense is less pronounced in the ULC community, which has not yet faced a disaster comparable to the 2013 Kédārnāth event; nonetheless, 17 of the 30 interviewees there do perceive the "nuisance" caused by dozens of seasonal rainfall-triggered landslides along the only road in the valley as a significant factor in decisions on out-migration.

Most interviewees in both communities believe that state-led improvements in modern education (28 of 30 in ULC, 24 of 30 in UM) and financial literacy (18 of 30 in ULC, 23 of 30 in UM) would generate economic possibilities that could foster greater resilience by enabling mass transitions to more urban livelihoods that are less exposed to geohazards. Two-thirds of all interviewees' households (20 of 30) in ULC and nearly all interviewees' households (29 of 30) in UM have at least one member with an educational attainment level higher than primary school; about one-third (11 of 30) in ULC and half (16 of 30) in UM also report vocational skills in their household that may be useful for livelihood diversification. However, few interviewees (4 of 30) in ULC have even one person in their household with a working knowledge of and access to some form of institutional credit; none of the interviewees in ULC express confidence about being able to raise a loan themselves. The situation is significantly better in the more commercialised pilgrimage-driven economic set-up of the UM community, where nearly all of the non-immigrant ethnic Garhwālī interviewees (22 of 23) claim to have at least one person in their household with a working knowledge of and access to some form of institutional credit, with a quarter (6 of 23) expressing some confidence about being able to raise a loan themselves. None of the 7 immigrant interviewees in UM express any knowledge of institutional lenders, but all of them recall having borrowed money from individual lenders in their home villages at estimated simple interest rates of 15-20% per annum.

Fewer than half of all interviewees in both communities (11 of 30 in ULC, 14 of 30 in UM) show some awareness of the possibility of using insurance as an instrument for managing disaster risk. Not surprisingly, therefore, insurance penetration remains very low, with only 4 of the 30 ULC interviewees and 9 of the 30 UM interviewees reporting at least one household member with an active life insurance policy (mainly Rural Postal Life Insurance, which is offered by India Post, the extensive state-owned post office network). None of the interviewees in either community reports being part of a household that has ever used or been aware of a crop or livestock insurance service.

To sum up, the economic component of the ULC and the UM communities' existing adaptive capacities is sustained mainly by their own ongoing autonomous adaptive actions such as out-migration and long-term transitions to financial investments, livelihood resources, and economic activities that are significantly less exposed to geohazards. These actions are responses not only to the physical risks operating in the communities' changing natural environments but also to the livelihood risks (see Forsyth and Evans 2013) that are constantly emerging from the interactions of purely environmental risks with concurrent socio-economic changes such as rapid shifts from traditional economic self-sufficiency to modernisation-induced dependencies on the global market. State-driven adaptive measures such as improving access to financial institutions and instruments do seem to have a long way to go in reducing risk and fostering economic resilience.

6.2.2.2. Aspirations for the future

Upper Lāchen Chú Valley

The vast majority of interviewees (24 of 30) regard community-led, community-centric tourism development as the key to strengthening the economic component of adaptive capacity in the ULC region. All of these individuals identify poor roads and the general lack of access to credit as the main obstacles to the growth of local tourism-based entrepreneurship in the region. Nearly half of all interviewees (14 of 30) also complain that the current state-controlled travel permit regime for tourists does not sufficiently encourage local enterprise in that it allows travel agencies based in Gangtok, the provincial capital, to capture a huge share of the market by providing one-stop holiday solutions such as three-day tour packages with transport, accommodation, guides and permits.

Many (12 of 30) also argue that the Army and the provincial and national governments should work together to ease the border security-driven prohibition on tourist access to all walking trails in the region (except the famous high-altitude Green Lake route, for which a very tedious permit system is in place) as this will open the way for new employment-generating activities such as guided hiking, yak-riding, horse-riding, rock climbing, and paragliding. Also, most interviewees (22 of 30) assert that the government's tourism development campaigns must vigorously and educatedly market the region's rich traditional culture (including local Buddhist monastic visual and performing arts as well as transhumant pastoralism and associated handmade products such as yak cheese, woollens, rugs, stool tops, hide boots and tents) as this can help revive locally cherished cultural practices that are becoming economically unviable or otherwise socially obsolete.

Three young men, Phuntsok, Gyurmey and Chökyi, discuss some of the economic needs and aspirations that are detailed above:

> *"Farm yields are going down, the climate is not great, and educated young people have aspirations… That's why tourism needs a boost… We need loans and better marketing. We need a direct link with customers in Kolkata, Delhi, Mumbai… And the government should open and advertise a few local trekking routes… One brother can run a lodge, another can organise yak and horse riding, another can be a guide... Their wives can make and sell traditional snacks and pickles and rugs… That's how tourism should happen. If a big earthquake were to hit Lachen or a flood were to destroy Thánggū, how would we stand up again? We have no treasure trove. We have nobody working in Gangtok or Bangalore… Well, we might have a few city cousins, but they can't be expected to help us…"*

> *"Luckily, we have a post office here. Many people have savings there… But I don't think the post office lends money… Only banks do, and the nearest bank is in Chungtháng… You've seen how many landslide-prone stretches there are along that road… You know it's not easy to get there… The government talks about self-employment, but you do need some money to make a start."*

> *"I think the government can help us financially by promoting adventure tourism and ecotourism in this area… Our valley is excellent for paragliding and rock climbing, and the Khángchendzöngā National Park is right here. But we need training, equipment and some cooperation from the government and the military. As of now, only one trekking route is open in the whole of North Sikkim, and that too is restricted through a very complicated permit system. They should promote trekking, horse riding and yak riding by opening up more trails. The WWF can teach our young people about local birds and plants and train them as ecotourism guides, but we cannot make use of all that unless tourists are allowed to travel off the main road. "*

Young people in the ULC community look at tourism-based self-employment as a more secure and sustainable livelihood alternative to agro-pastoral pursuits, especially in view of the increasingly more extreme regional climate. They expect the government to support local tourism-based entrepreneurship in three ways – by improving access to credit; by easing the border security-related tourism permit regime, including stringent restrictions on trekking or any other touristic activity off the main road; and by marketing the culture, wilderness, and adventure potential of the region more effectively.

Upper Mandākinī Valley

In addition to livelihood diversification within the farming sector (e.g. horticulture), non-agricultural employment opportunities outside the region or in geophysically safe environments within the region for men (26 of 30 interviewees) and within or not far from the village for women (19 of 30, including 11 of 13 females, 8 of 17 males) are regarded by most interviewees as the key to expanding adaptive capacity.

A steadily growing decentralised community-based co-operative weaving initiative for women, especially those who lost male breadwinners during the 2013 disaster, is hailed by many (14 of 30 interviewees) as an icon of adaptive capacity building in the region. That the enterprise provides part-time remunerative work to about 300 women in all-female environments within the limits of their own hamlets makes it culturally non-disruptive – it enables women to earn their living and support any dependent children in a socially sanctioned manner (i.e. without being stigmatised) while fulfilling household and farming commitments (10 of the 13 female interviewees); it also serves to eliminate or soften the occasional patriarchal requirement for a young widow to be remarried to her deceased husband's brother, often at least partially against her own wishes (7 of 13), or for a very young, barely marriageable-aged woman to be hastily, and often distressfully, married off following her father's death (3 of 13). According to the records of the district administration at Rudraprayāg, the hamlets in the UM valley have at least 296 married women and 89 unmarried females aged 15-25 years, who lost their breadwinning husbands and fathers, respectively, during the 2013 disaster.

Rūpā and Lakshmī are both disaster-widowed mothers in their thirties. Upon gaining employment with the local weaving enterprise, they have become the first-ever female wage earners in their families. Apart from the immense psychological and social benefits of their work, they are particularly pleased with its capacity to secure the future of their vulnerable children:

> *"At that time [just after the disaster], I would just stay at home… It was like… How do I get going? Then, when Brother started this [community weaving enterprise]… I started to go out… It made me stronger… I now weave for four hours each day. I am living with dignity… My child is everything now... That's all that there is… I mean, whatever had to happen to me has happened… Now the child has to be given a good education, a good upbringing, good nourishment… For that, I have to earn… You need cash for everything… Household bills are huge… If I don't work, how will it all be managed? When I look at my child, I feel I have to stand up again for him… When my husband has left him to my care, I can't desert him. If I too go missing, what will the child's future be? Won't he be called an orphan?"*

"It's no use getting stuck in the sorrowful past. Before, my husband was the breadwinner, and I would just do some farming and household chores… Now… our breadwinner is no longer with us, so I have to manage everything on my own… No matter what, the children have to move forward… I have to see to their education. and set their future on the right track. What we have had to go through must not be allowed to fetter the children's future. I can't let my suffering afflict them… When all the weaving women get together… we talk about our lives, express our sorrows, share our pain… We feel unburdened, and that helps us weave better. We are not just weaving cloth here; we are weaving new lives, new hopes… just for our children!"

The vast majority of interviewees (23 of 30) also speak of the need for young people to be able to raise capital for self-employment (e.g. opening a shop or lodge for pilgrims, buying and operating a commercial vehicle, or starting a home-based manufacturing enterprise), especially in view of the high level of competition for government jobs in the region. Some (11 of 30) see NGOs and corporate social responsibility projects, as opposed to governmental agencies, as potential providers of self-employment opportunities and entrepreneurial training. This, according to Vishnu, who is in his early twenties and "desperate for a decent job", can make the community more economically self-reliant:

"I think we need to prepare ourselves for more disasters. We can't rely on the government… We can't rely on anybody but ourselves. If we are wealthy, we will be strong… We need to create more sources of income for ourselves… I don't know how, but we need to do this. Perhaps big people from cities, NGOs can help with this… Also, our people don't know much about insurance and money things… earning interest, raising loans… Perhaps some organisation could train our young people in all that…"

Many interviewees argue that an education that provides fluency in English (25 of 30), basic computer and financial skills (19 of 30), "urban shrewdness" (19 of 30), and a confident *chāl-dhāl* or body language and attitude (16 of 30) is the most pressing need facing young people, most of whom aspire to enter formal employment outside the village, particularly in lowland cities such as Rishikesh-Haridwar, Dehradun, and the National Capital Region of Delhi.

Much of the above discussion on the economic dimension of adaptive capacity is oriented towards preparing for long-term disaster recovery rather than immediate response. What follows is a review of both communities' appraisals of the logistical aspects of adaptive capacity in the context of practically facing climate-related geohazards on the ground.

6.2.3. Logistical factors

6.2.3.1. Upper Lāchen Chú Valley

Most ULC interviewees think that it is necessary (24 of 30) and possible (17 of 30) for the community to prepare for a future disaster from an immediate-term response standpoint. The Army and the ITBP (paramilitary force), whose camps and logistical resources (vehicles, rescue equipment, medical supplies, satellite-based communication equipment, trained personnel, etc.) are present throughout the ULC valley, are seen by almost all interviewees (28 of 30) as the primary and most reliable source of immediate help in the event of a disaster. The district-level civilian administration is regarded as a secondary source of support in the very immediate aftermath of a disaster, but as the key actor in the delivery of relief, recovery support, and rehabilitation at subsequent stages.

Many interviewees (12 of 30) strongly express the need for the community and its *dzumsá* (local self-government body based in Lāchen) to be self-reliant in disaster response, mainly in view of the ULC valley's geographical remoteness and the accessibility challenges it poses, for example, in the event of an extreme monsoon rainstorm preventing helicopters to fly into the valley while also triggering several dozen landslides along the 87-kilometre/5-hour road stretch between the community at Thánggū and the district headquarters at Mangan.

Remarkably, no interviewee (0 of 30) has received formal training in disaster response or is aware of any action plan that could be followed in the event of a village-wide emergency; only 3 of the 30 interviewees report having acquired potentially useful disaster response skills during the 2011 earthquake, and an equally small proportion (3 of 30) have considered devising a response plan for their own households. Very small fractions of interviewees report having household-level access to first aid kits (2 of 30) and improvised rescue equipment (3 of 30). Although all interviewees (30 of 30) are part of households that traditionally store surplus food that would last four weeks or longer, none of those in Thánggū-Lhāshar (0 of 19) are confident about being able to access safe drinking water immediately after a major flash flood or debris flow disaster.

There is no civilian phone connectivity, television, or Internet in Thánggū-Lhāshar, but some access to only inward mass communication via AM/FM radio. When in Lāchen, however, all interviewees and their families generally have good mobile phone connectivity as well as access to television. Also, nearly half of all interviewees (14 of 30) own smartphones, through which they can generally access 3G Internet in Lāchen (where WhatsApp is emerging as a popular medium for the circulation of local news and public information announcements). Even so, no interviewee reports having household-level access to a means of inward or outward telecommunication that would not normally fail in the event of a rainstorm-triggered electricity supply disruption, including to the mobile phone tower in Lāchen. Satellite phones are, nonetheless, present at local Army and ITBP camps.

Jigdel, a middle-aged cattle herder, highlights the need for a well-thought-out hamlet-level disaster response plan and a reliable emergency communication system that would enable government agencies such as the State Meteorological Centre in Gangtok to instantly transmit disaster risk warnings directly to the community:

> *"We can't just take these things as they come; we need to have a plan! Each member of the community must know how to respond to an emergency… Also, we need some sort of warning system with a direct link to the weather department in Gangtok [provincial capital]. The Army and ITBP are here, so we don't worry about these things… But the community needs to be prepared… We should be able to protect our own lives and homes."*

Jigmé, a middle-aged yak herder and community leader, makes a more detailed assessment of the community's logistical resources, highlighting the need for greater self-sufficiency in disaster response, especially access to civilian healthcare facilities:

> *"We need some sort of warning system, especially for Thánggū. I know the Army and ITBP are there to help our people, but we need our own resources too. The* dzumsá *should be able to coordinate emergency actions… There are so many things that we don't even think about – for example, how will we get safe drinking water if there is a big storm and all our water become mud… Then there is the usual mobile phone problem – when there is a storm, there is no electricity; when there is no electricity, mobile towers don't work unless they are made to run on a diesel generator… But is there a generator? Do they store enough fuel for a three- or four-day power cut? I don't know… Hopefully, Lāchen will have a hospital within the next five or seven years. But we will also need trained nurses and resident doctors. The Army people have their own medical staff and everything, and they are generally happy to help us, but that may not be enough if there is a big disaster… I think it is really important for us to have our own stuff…"*

Despite comprising more than 330 and 60 households respectively, Lāchen and Thánggū are (at the time of fieldwork in the autumn of 2015) about 26 km (~1.5 hours) and 58 km (~3.5 hours) away by road from the nearest primary health centre (sub-district headquarters at Chungthang), and about 55 km (~3 hours) and 87 km (~5 hours) away from the nearest hospital (district headquarters at Mangan). The above travel times can be far greater in the June-September monsoon season, when rainfall-triggered landslides often block the road. This lack of access to civilian healthcare, according to 18 of the 30 interviewees in the community, is the most pressing development issue in the ULC valley.

Half of all ULC interviewees (15 of 30) also believe that, from a disaster response standpoint, it would be sensible, convenient and cost-effective for the government to revitalise and make infrastructural investments in the community's rapidly declining traditional system of herbal medicine, considering that it relies on locally available plant materials, local ecological knowledge, and keen practitioners from within the community rather than "imported medics who are on punishment postings". Middle-aged Pembā enthusiastically shares his knowledge of local medicinal plants and their socio-economic situation:

> *Our elders used to treat all ailments only with medicinal herbs collected from local forests and meadows. Today's young people aren't aware of the amazing, life-saving plants that grow in their own backyards, but they travel all the way to the city to buy stony pills made by machines... I myself know so much less than my parents, but I can recognise the four most useful roots - the warmth-inducing Tiktā or Kurkī for coughs and colds, the vomit-inducing Bikmā for poisoning from food, the germ-destroying Ombolāko or Pānch Amlī for wounds, and the pain-relieving Chüká or Sikkim Sundarī for bone troubles… By the way, we also make a delicious pickle out of the stem of Chüká… What everyone still knows about is Yartsa Gunbu [caterpillar fungus], the great aphrodisiac and dispeller of fatigue. Well, that's because the Chinese love it too much and pay too much for it!"*

An additional logistical factor in preparedness for disaster response is drunkenness, chiefly but not solely among men, which might considerably hinder evacuations if a disaster event were to take place between late afternoon and early morning. More than half of all interviewees (17 of 30), including all 8 females, identify male alcoholism as a significant social issue in the community, particularly in Thánggū, where "it is often too cold or wet to be outdoors, and there is little to do indoors". Two-thirds of all interviewees (20 of 30) emphasise that drunkenness is the most pronounced in the wettest weather, when people have no choice but to remain indoors. Coincidentally, such times are also when the probability of an extreme rainfall-triggered disaster striking the community is the greatest.

6.2.3.2. Upper Mandākinī Valley

The vast majority of UM interviewees think that it is necessary (27 of 30) and possible (21 of 30) for the community to prepare for a future disaster from an immediate-term response standpoint. Nearly three-fourths (22 of 30) of all interviewees report having acquired potentially useful disaster response skills during the 2013 disaster. Notably, however, none of the interviewees have received any formal training in disaster response or are aware of any emergency action plan that could be followed in case of a disaster (though a very few (4 of 30) have recently considered devising a plan for themselves and their families). Few interviewees report household-level access to first aid kits (3 of 30) and improvised rescue equipment (5 of 30). Even though more than half of all interviewees (16 of 30) are part of households that store surplus food that would last four weeks or longer, none of them are confident about being able to access safe drinking water immediately after a 2013-type disaster event.

No interviewee reports household-level access to a means of telecommunication that would not fail if a 2013-type disaster occurred on the day of the interview; however, satellite phones have been available for public use at three locations on the pilgrim trail to Kédārnāth since the 2015 pilgrimage season. The district administration also reports having partnered with a private IT services firm to implement a game-changing ISO 9001:2008-certified information and communications technology project along the Kédārnāth pilgrim trail. This will involve the use of an unlicensed radio frequency band and sensors installed at seven different locations along the trail to operate a local wireless intranet system, which will be connected to a government-owned mobile phone tower and will facilitate WiFi Internet access, hotline communication and video-conferencing between administrators, and video surveillance enabled by a network of cameras covering the entire pilgrim trail. Radio frequency identification sensors will be deployed to track the movement of mules and horses hired by pilgrims through the government-managed prepaid service. In addition, the district administration has recently collaborated with a private GIS and IT consultancy firm to launch the freely downloadable Shri Kedar Rescue android application for mobile phones, using which stranded persons should be able to track their own location, access relative locations of emergency facilities such as the nearest helipad or police and medical posts, and instantly send distress messages with locational information to the District Emergency Operation Centre.

Remarkably, as of the summer of 2016, none of the community interviewees express any awareness of the above developments, with some dismissing them as "gimmicks to impress city pilgrims and politicians". Govind, a middle-aged farmer and contractor, complains:

> *"I don't know anything about this Internet, Phinternet, or whatever it is! We're totally unprepared for another disaster. We have no plan, nothing! How will they warn us? Can anybody warn us? They might give us a bad weather warning, but how will they save us and thousands of pilgrims? We need to think about this seriously… God helps those who help themselves... The government only cares about its image in the outside world… about its reputation in the eyes of pilgrims from Delhi, Mumbai and Gujarat… about what all the news channels think of it… We can't rely on the government or anything it says!"*

There are similar concerns about access to healthcare. During the May-October pilgrimage season, basic medical facilities (including supplemental oxygen cylinders for managing altitude sickness among pilgrims) are available at Kédārnāth (which has ~300-612 seasonal non-pilgrim residents and a few thousand pilgrim visitors each day) as well as other locations on the pilgrims' trail, and at the 1,400-strong village of Trijugīnārāyan nearby, which does not have a hospital or even a year-round primary health centre of its own. None of the seasonal health facilities is focused on the needs of the local community, seems sufficiently equipped to deal with critical cases, or has the capacity to concurrently attend to more than a dozen minor casualties. If helicopter evacuations were not possible (for example, in the event of a major monsoon rainstorm, which could cause aircraft to crash, as it did several times during the 2013 disaster rescue operations), the nearest full-fledged hospital (located in the town of Rudraprayāg) would be a 5-8-hour arduous walk (16 km) plus at least a 4-5-hour drive (72 km) away from Kédārnāth. If the relatively narrow and rickety road were to be temporarily blocked by monsoon rainfall-induced landslides or even by the usual kilometres-long traffic jams associated with the several thousand pilgrims who arrive and depart each day, it would become completely impossible to save the lives of critical patients.

Overall, the adaptive capacities of the ULC and UM communities in the context of being able to undertake immediate-term disaster response measures are inadequate, especially due to limited local-level access to key logistical resources and critical infrastructure. All the logistical elements of communities' adaptive capacities appraised above are directly related not only to economic resources but also to governance-related factors such as state policies, legislative actions, and plans vis-à-vis disaster reduction and climate change adaptation. The following paragraphs delve into these.

6.2.4. Governance-related factors

No interviewee in ULC or UM shows much familiarity with the policy, legislative, or development planning frameworks within which the national, provincial, and district-level governments support communities in managing disaster risk and adverse impacts of climate change. An emic appraisal of these aspects of the communities' adaptive capacities would, therefore, be of limited practical value. What is attempted here instead is a brief etic review of the Indian state's key disaster risk governance frameworks, albeit one that is cognisant of the specific local experiences of hazards and vulnerabilities in ULC and UM.

India promulgated its very first law on disaster risk governance, the Disaster Management Act 2005 (Parliament of India 2005), following the World Conference on Disaster Reduction in Kobe, Hyogo, Japan, where the Hyogo Framework for Action 2005-2015 was adopted with the intention of substantially reducing "disaster losses, in lives and in the social, economic and environmental assets of communities and countries" (UNISDR 2007, p. 3). Responding to the Hyogo Framework's call for the creation of a robust institutional mechanism for disaster risk reduction at multiple levels of government within each country, the Indian legislation mandated the establishment of a National Disaster Management Authority (NDMA, headed by the Prime Minister) at the federal level, State Disaster Management Authorities (SDMAs, chaired in each province by the respective Chief Minister, the elected head of government), and District Disaster Management Authorities (DDMAs, led in each district within each province by the Deputy Commissioner or District Magistrate, the most senior civil servant in that district). Among other roles, the Act tasked the NDMA, SDMAs, and DDMAs with preparing comprehensive national, provincial, and district-level plans for disaster management. It also required the establishment of a National Institute of Disaster Management for research, informatics support, and training in the field of disaster management and reduction; a specialist, federally commanded National Disaster Response Force that would be deployed for immediate ground response in disaster situations; and separate funds for disaster response and disaster mitigation at the federal, state, and district levels.

The Act of 2005 focuses mainly on creating an efficient top-down, bureaucratically controlled administrative framework for immediate disaster response (i.e. evacuation, rescue and relief), rehabilitation, and reconstruction. Although it does acknowledge that disaster preparedness and prevention fall within the purview of disaster management, it seems to shy away from multiplex commitments such as creating mechanisms for cross-sectorally mainstreaming disaster risk reduction into the wider practice of sustainable development, building resilience and adaptive/transformative capacities in the context of livelihoods, and democratising disaster management by ensuring the active and equitable participation of communities and non-governmental actors. Nonetheless, these issues are addressed to a considerable extent by India's National Policy on Disaster Management (NDMA 2009) and the recently devised National Disaster Management Plan (NDMA 2018), which was first released in 2016, more than a full decade after the 2005 Act prescribed its formulation.

Incidentally, the severe delay in its preparation has allowed the National Plan to benefit from the holistic, people-centric approach to disaster risk management that is being promoted globally by the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015), the successor to the 2005-2015 Hyogo Framework. The Sendai Framework is aimed at reducing disaster risk and losses not only in lives but also in livelihoods and well-being; not only in physical, economic, social and environmental assets, but also in cultural resources; and not merely at the national level, but also directly for individuals, their enterprises, and their communities. So as to achieve the above outcome, the Framework commits to a fairly all-encompassing goal: "Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience." (UNISDR 2015, p. 12).

In keeping with its integrative character, the Sendai Framework emphasises the need for participatory, culturally appropriate, and context-specific modes of disaster management that use local, traditional and indigenous knowledge systems and practices to complement Western science in understanding, assessing, preparing for, governing, and reducing risk. This need is acknowledged but still not genuinely and tangibly addressed by the National Disaster Management Plan or the National Policy on Disaster Management, probably as a result of the centrally controlled, bureaucratically operated Western science-based model of disaster risk governance enshrined in the 2005 Act.

The Sendai Framework also recognises the need to appreciate and manage the complex interactions among underlying drivers of disaster risk such as a warming and more variable climate, rapid modernisation and urbanisation, and inequitable economic development and poverty. In response to this recognition at the global level, India's new National Disaster Management Plan (NDMA 2018) advances a rounded, livelihood-focused approach to reducing risk and building long-term resilience that draws upon the synergies among the post-2015 global agendas on development, climate change, and disasters – the Sustainable Development Goals (UN 2015), the UNFCCC Conference of Parties 21 Paris Agreement on Climate Change (UNFCCC 2015), and the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015). However, such integrated planning is yet to be put into practice, for example, through the establishment of robust, institutionally supported linkages between the National Disaster Management Plan and the National Action Plan on Climate Change.

India's fairly rudimentary National Action Plan on Climate Change (Prime Minister's Council on Climate Change 2008), which has not been reviewed or updated over the past decade, largely overlooks climate change-related geophysical risks and their management. It does not explicitly address disaster risk reduction as one of its eight key thematic "missions" (expansion of solar power generation, improvements in energy efficiency, urban sustainability, water resource management, afforestation, sustainable agriculture, environmental monitoring across the Indian Himalaya with a focus on glaciology, and capacity building in climate change research and knowledge management) or even as a background theme that cuts across a few missions. Although the plan does briefly touch upon disaster management as a miscellaneous concern, it fails to develop a comprehensive adaptive capacity-building strategy that intensively incorporates disaster risk reduction practices into climate change adaptation.

A similar lack of strategic coherence is seen at the provincial level in Sikkim, whose adaptation-oriented State Action Plan on Climate Change for 2012-2030 (Government of Sikkim 2011) does not include the management of climate-related disaster risks as one of its key priority areas or as a salient cross-sectoral theme. The plan focuses instead on the discrete subjects of water security, agriculture, forests and biodiversity, and urbanisation (see also Jogesh and Dubash 2014). Somewhat contrastingly, Uttarakhand's State Action Plan on Climate Change (Government of Uttarakhand 2014), which was developed immediately after the extreme precipitation-triggered June 2013 disaster, conspicuously emphasises disaster management as an integral component of its approach to climate change adaptation. It does not, however, build meaningful strategic and administrative connections between action on climate change adaptation and provincial- and district-level disaster management plans.

The linkages among sustainable and equitable human development, environmental change management, and disaster reduction are especially consequential in the particular context of ULC (Sikkim) and UM (Uttarakhand), where remote, rapidly modernising/developing societies/economies are faced with hydrometeorologically triggered geohazards in a rapidly changing climate. However, the ground situation in the two regions does not reflect any significant mainstreaming of climate change and disaster risk concerns into infrastructural and livelihood development planning at the district, sub-district, and village levels. Moreover, the National Disaster Management Plan's crucial shift of emphasis from short-term loss minimisation towards long-term, all-round adaptive capacity development has yet to substantially filter down to the provincial, district-level, and local bodies that currently govern disaster risk in ULC and UM.

The province of Sikkim does have a fairly comprehensive State Disaster Management Plan with separate volumes on disaster risk reduction and mitigation (Sikkim SDMA 2015a), disaster response (2015b), inventories of logistical and informational resources (2015c), and specific action plans for governmental line departments and non-governmental stakeholders (2015d). However, despite the importance it gives to cross-sectoral risk reduction and preparedness, the attention it pays to fostering long-term economic, social, and cultural resilience seems inadequate. Uttarakhand's State Disaster Management Plan (Disaster Mitigation and Management Centre 2015, Uttarakhand SDMA 2015) seems even less state-of-the-art in that it remains oriented towards immediate disaster response and relief, and its engagement with preparedness seems limited to short-term loss and damage reduction. District Disaster Management Plans in both regions are rudimentary, tend to be virtually limited to response and relief measures, and are essentially lists of governmental actors that would be mobilised in a disaster situation. Remarkably, no risk reduction plans or even standard operating procedures for disaster response exist at the level of the local community. Besides, none of the local government bodies – the Lāchen Dzumsá (traditional village council) in ULC or the Kédārnāth Nagar Panchāyat (semi-urban town council) and Grām Panchāyats (village self-government bodies) in UM – have access to geophysical hazard assessments or socio-economic, cultural and ecological vulnerability assessments that have been conducted at spatial scales large enough for practically useful risk management interventions within each settlement.

While a thorough province-wide hazard mapping exercise has not been completed in Uttarakhand, the fairly comprehensive GIS-based district-level hazard database for Sikkim (Sikkim SDMA 2012) offers 1:50,000 as the largest spatial scale of assessment, which implies that a settlement is seen as a single dot on a printed map, and, therefore, little can be determined about hazard exposures within the settlement. Hamlet-level risk mapping (at scales ranging from 1:20,000 to 1:5,000 or larger) will be possible only when investments are made in such activities as obtaining very high-resolution environmental data from remote sensing agencies and employing researchers or partnering with local communities themselves to collect adequate ground-level terrain data and household-level social data. Besides, although the State Disaster Management Authorities (SDMAs) in both Sikkim and Uttarakhand claim to have a "multi-hazard approach" to disaster management, this is yet to be achieved in practical terms. Little effort has been made towards spatially analysing inter-hazard interactions (beyond simply overlaying individual hazard susceptibility layers) in region-wide geographic information systems (GISs) to generate truly composite assessments of multiple hazards that operate together over the same spaces. Even less progress has been made towards spatially combining multi-hazard data with socio-economic and cultural vulnerability data in region-wide GISs to produce comprehensive risk maps, and no attention has been paid to the possibility of participating with local communities to incorporate their traditional, context-specific geographical knowledge (e.g. spatially and geomorphologically referenced folklore) into risk appraisals.

In the absence of effective land use planning and regulatory interventions based on authoritative local-scale risk mapping and zonation, haphazard construction activity has been allowed to take place at locations that are visibly exposed to hazards such as flash floods or landslides. This has heightened existing risks and created new risks in both ULC and UM. Despite provisions for penalties in the Disaster Management Act, a culture of governmental accountability for risk magnification does not seem to have been established, especially in the province of Uttarakhand, where the hydrometeorologically triggered June 2013 disaster was able to cause damages worth over US$ 661 million (JRDNA Team 2013) besides thousands of fatalities.

Following the 2013 disaster in Uttarakhand, an audit of governmental effectiveness in managing risk revealed a wide range of grave governance failures, especially on the part of the provincial government (Comptroller and Auditor General of India 2015). Most importantly, Uttarakhand or any of its districts virtually did not have any disaster management plan in place at the time of the disaster; nor was there a legally mandatory national-level disaster management plan for India at the time, even though more than seven years had passed since the enactment of the Disaster Management Act 2005. Although constituted in 2007 as per the 2005 Act, the Uttarakhand SDMA had not framed any policy, action strategy, or guidelines in respect of disaster management or risk reduction during the several years of its existence before the 2013 disaster. Also, Uttarakhand's State Executive Committee, a provincial-level bureaucratic body that was legally responsible for advising the Uttarakhand SDMA on disaster management and implementing (the then non-existent) national and provincial disaster management plans within the state, had not met since its institution in 2008.

Owing to poor planning, the various line departments of the provincial government in Uttarakhand were ill-prepared and ill-equipped for disaster response in 2013. The above audit found that governmental response at all stages - over the two days of heavy rainfall that preceded the disaster, during the disaster itself, and in the immediate and medium-term aftermath of the disaster - was seriously hampered by the absence of properly designed standard emergency operating procedures for individual departments, a robust mechanism for inter-departmental communication and coordination, adequate human resources and search and rescue equipment at the state and district-level Emergency Operation Centres, sufficient stockpiles of food and medical supplies at the district or local level, and telecommunication and transport systems that would not completely fail during inclement weather conditions in mountainous terrain. Besides, the audit discovered that the disbursement of financial aid to disaster-affected families had been delayed by between one and six months in as many as 49% of the 33,488 filed cases of human fatalities and major livestock losses in the Uttarakhand state and 52% of the 7,065 filed cases in the UM community's Rudraprayāg district alone; for pay-out delays of more than six months, the corresponding figures were 24% in the whole of Uttarakhand and 5% in Rudraprayāg (Comptroller and Auditor General of India 2015, p. 40).

Overall, the adaptive capacities of the ULC and UM communities in the context of risk governance seem to be constrained to a greater extent by administrative inefficiencies, low levels of accountability, a general lack of coordinated action at all levels of government, and inadequate community participation and enfranchisement than by the intrinsic shortcomings of legislative and planning frameworks. The 2013 disaster in Uttarakhand has revealed many glaring gaps even in India's basic disaster response machinery, which must be filled before the focus of risk governance shifts towards fostering long-term, all-round resilience in the face of the complex interactions among changing environmental, socio-economic, and cultural realities.

6.3. Conclusion

This chapter opens with an analysis of rich ethnographic data from the two case studies, demonstrating the behavioural potency of deep-seated metaphysical convictions, moralities, and emotionalities vis-à-vis traditional communities' engagements with environmental risk. By that means, it underlines the critical need for emically examining culturally rooted mass-psychological phenomena as part of adaptive capacity assessments, especially in the context of indigenous societies interacting with extreme geophysical environments. While drawing the reader's attention to the above psycho-cultural factors as a neglected but ineluctable dimension of adaptive capacity, the chapter also acknowledges that practically efficacious, livelihood-focused adaptive strategies cannot be developed without adequately engaging with tangible (and therefore conventionally addressed) socio-economic and managerial issues. These "worldly" aspects of adaptive capacity encompass such factors as social structures and relationships, economic assets and opportunities, logistical resources and critical infrastructure, and governmental planning and risk governance machineries.

The analysis finds both the ULC and the UM communities to be psycho-culturally resilient in terms of the role of their traditional Buddhist/Hindu metaphysical beliefs in enabling a kind of emotional-spiritual self-immunisation against environmental and social risks. It also finds the communities' social capital, especially high levels of clan-based cohesiveness and cooperativeness, to be contributing significantly to their inherent adaptive capacities. Although the analysis does not focus on adaptive capacity differentials within the communities, it does find that in the UM community, non-priestly-caste immigrant manual workers from non-native ethnic groups tend to be more exposed to geohazards than the rest of the community, while also holding significantly smaller adaptive capacities in terms of social support and economic assets. Besides, due to gendered social roles, most females in both communities tend to be financially dependent on male breadwinners, thereby possessing smaller socio-economic adaptive capacities than males. However, men tend to be more exposed to geohazards due to their more outdoor-based occupations.

The economic component of both communities' existing adaptive capacities is embodied largely by their own autonomous adaptive practices such as out-migration in search of physically and financially secure urban employment as well as long-term transitions to financial investments, livelihood resources, and economic activities that are significantly less exposed to geohazards. These practices are responses not only to environmental risks but also to the livelihood risks that are constantly emerging from the interactions of purely environmental risks with concurrent socio-economic changes such as rapid shifts from traditional economic self-sufficiency to modernisation-induced dependencies on the global market.

State-driven economic support measures such as improving access to credit for livelihood diversification and local entrepreneurship development seem to have a long way to go in enhancing the communities' adaptive capacities. The state also has much to do in respect of improving the remote communities' access to critical infrastructure (especially healthcare and rainstorm-ready transport and telecommunication systems); equipping them with key logistical resources for disaster response; enhancing their participation and enfranchisement in adaptive planning and risk governance processes; and tackling wider administrative issues such as poor inter-departmental coordination, low levels of bureaucratic efficiency and accountability, and limited devolution of powers to village-level self-government bodies. It is to be noted here that owing to modernisation-induced economic self-insufficiency as well as financial, administrative, and political dependencies on the somewhat centralising state, a significant portion of local adaptive capacity lies beyond the communities themselves. Due to the geographical remoteness of the communities, this poses a particular challenge for adaptation on the ground.

This chapter has so demonstrated the profound multi-dimensionality of adaptive capacity. A full assessment of adaptive capacity necessitates working with multiple, intrinsically different kinds of knowledge and understanding, and then finding a way to meaningfully integrate them so that they may benefit adaptive practices on the ground. The next chapter develops an integrative framework that draws upon ideas from practice theory to systematically synopsise the extended appraisal of adaptive capacity undertaken in this chapter. It does so with a view to making this dissertation's analysis more usable and transferable in terms of the development of a strategic schema for climate change adaptation and disaster risk reduction.

7. Aiding adaptation

As well as advancing a holistic, culturally responsive epistemology of climate change-related geohazards, the preceding chapters detailed a wide range of psycho-cultural, social, economic, logistical, and governance-related factors that constitute the two case study communities' adaptive capacities in the face of those hazards. This chapter seeks to use that extensive, multi-dimensional assessment to develop an integrative strategic framework for expanding adaptive capacity and reducing vulnerability in ways that appreciate the complexities of lived experiences of environmental risk. In order to do so, Section 7.1 first proposes *AdapT*, a conceptual model that characterises adaptive capacity in a practically oriented manner – one that advances environmental risk management on the ground by focusing on adaptive *practices* that lie at the intersection of process-centric resilience building and actor-centric vulnerability reduction (see Section 2.2.2). This involves framing adaptive capacity as the capacity of a community to reduce (enhance) its own vulnerability (resilience) by undertaking practices that maintain, incrementally modify, or radically transform its functional character in the face of geohazards operating within the context of rapid climatic and social change (see Section 2.2, Pelling 2011). Section 7.2 uses this practice-based conceptualisation of adaptive capacity to generate a strategy-focused summary review of the adaptive capacity appraisal undertaken in Chapter 6. It is upon this review of the case study communities' capacities to undertake risk-reducing adaptive practices as well as the empirical work on understandings of risk throughout Chapters 4-6 that Section 7.3 attempts to abstractively build a holistic strategic framework for locally appropriate climate change adaptation and disaster risk reduction, especially among traditional, remote developing societies.

7.1. The *AdapT* model: A practice-based characterisation of adaptive capacity

Stemming from the theoretical ideas presented in Section 2.2.2, the empirical analysis of risk undertaken in Chapters 4 and 5, and particularly the detailing of grounds for adaptive capacity in Chapter 6, the current discussion attempts a practically oriented conceptual integration of vulnerability and resilience in which adaptive capacity plays a pivotal role. To this end, the *AdapT* model is proposed, which is visually represented in Fig. 7.1 as a three-dimensional T-shaped structure.

In Fig. 7.1, two intersecting cubes form the head of the 'T'. The red cube on the left hand side, along with the entire trunk of the T, represents resilience. The blue cube on the right, along with the entire trunk of the T, represents vulnerability. The overlapping halves of the two cubes, along with the entire trunk of the T, represent adaptive capacity (see also Cutter et al. 2008, Engle 2011).

Resilience is conceptualised in *AdapT* as comprising two elements - adaptive capacity and *intransigence* (left half of red cube). Adaptive capacity is broken down into three constituents, arranged in a column - *persistence capacity* at the top (right half of red cube/left half of blue cube), *transition capacity* in the middle, and *transformation capacity* (equivalent to Walker et al.'s (2004) *transformability*) at the bottom of Fig 6.1. These constituents correspond, respectively, to the three levels of adaptation discussed in Pelling (2011) - adaptation for [system-maintaining] resilience (confined to functional persistence), for transition (more pervasive but incremental change), and for transformation (radical change). Persistence capacity (embodied by system-maintaining resilience) spreads beyond the column, occupying the entire red cube. Intransigence (conceptualised here as the capacity to resist change and thereby block adaptation) is the part of persistence capacity that lies outside adaptive capacity, and therefore represents the component of resilience that does not extend into adaptive capacity. Accommodating Walker et al.'s (2004, 2006) view of [system-maintaining] resilience as not necessarily desirable, intransigence is portrayed here as the negative dimension of resilience. Coping capacity (lower half of red cube in Fig. 7.1) is regarded as a subset of persistence capacity. It is split between adaptive capacity and intransigence because not all coping is adaptive; arguably, basic short-term system functioning may sometimes be achieved by completely resisting change, even if that adversely affects the system in the medium or long run.

Although the model incorporates transition and transformation capacities into resilience (this study proposes the term *deep resilience* for this conceptualisation), it is adaptable to the traditional system-maintenance view of resilience (this study suggests the term *surface resilience* for this conceptualisation). Surface resilience will be represented by the red cube (persistence capacity) alone, and will not include the trunk of the T; adaptive capacity will not be a subset of surface resilience.

Vulnerability (equivalent to Brooks' (2013) biophysical vulnerability: see Section 2.2.1) is shown in *AdapT* as consisting of three elements - *sensitivity* (upper right quarter of blue cube) and *exposure* (lower right quarter of blue cube) to hazard, and *adaptive capacity* (ideally, incapacity, i.e. the inverse/reciprocal of capacity, because vulnerability, a negative property, is inversely related to adaptive capacity, a positive property). As mentioned earlier, adaptive capacity has three constituents, arranged in a column - persistence capacity at the top (left half of blue cube/right half of red cube), transition capacity in the middle, and transformation capacity at the deepest level.

The black arrows, projecting in Fig. 7.1 from resilience and adaptive capacity into exposure and sensitivity, denote the following idea: As adaptive capacity (positive *deep resilience*) expands, exposure and/or sensitivity shrink, leading to a decline in vulnerability. Theoretically, this can continue until vulnerability is obliterated (the blue cube is subsumed into the red cube, and the trunk of the T becomes so wide that the T turns into an inverted L) (Engle 2011, Kaul and Thornton 2014). As resilience uses the power of adaptive capacity to consume vulnerability, the entire middle column widens (en masse) in the direction indicated by the black arrows.

The three elements of practices discussed in Section 2.2.2 (Shove et al. 2012) – *materials*, *competences*, and *meanings* - are also embedded in the model. Practice-shaping interactions among these elements are indicated by the grey arrows drawn across their permeable (broken-line) boundaries in Fig 7.1. The interactions among materials, competences, and meanings – both locally/traditionally sourced and imported from modern/Western societies in the context of the case studies – occur across all layers of adaptive capacity, generating *system-maintaining, system-modifying*, and *system-transforming* practices. Interestingly, a practice might be performed at one level, and might expedite or even impede adaptation at another level (see Pelling 2011). For example, crop insurance is a practice that indemnifies farming households against financial losses from crop failure caused by environmental extremes, and therefore enhances *persistence capacity*. However, by absorbing environmental shocks and transferring risks in the short term, it might prevent farmers from modifying their farming systems (e.g. making a *transition* to new, potentially more successful crops or farming practices) or giving up farming altogether and trying out something potentially more profitable (*transforming* their livelihoods).

Each practice element in the *AdapT* model can be studied individually as a constituent or determinant of adaptive capacity - this is desirable from the atomistic, actor-focused vulnerability perspective on risk. At the same time, links between practice elements, each of which is a process of interaction, can be examined in relation to the adaptive practice, the entire bundle or complex of adaptive practices, or the entire meta-bundle or meta-complex of adaptive practices that embodies the adaptive capacity of the system - this kind of dynamic, multi-scalar process-centric assessment is desirable from the holistic, system-focused resilience perspective on risk. It is by uniting these two perspectives that this practice theory-based model provides a deep insight into adaptation. The focus is on adaptive practices in their entirety, which means that primacy is given neither to the elements of adaptive practices nor to the web of active links among them, neither to agency nor to structure. Fig. 7.2 illustrates how adaptive practices, contained within adaptive capacity, could potentially be mapped through a complex web of interactions among materials, meanings and competences. This is a tentative scheme; it may be refined and more fully operationalised in future research.

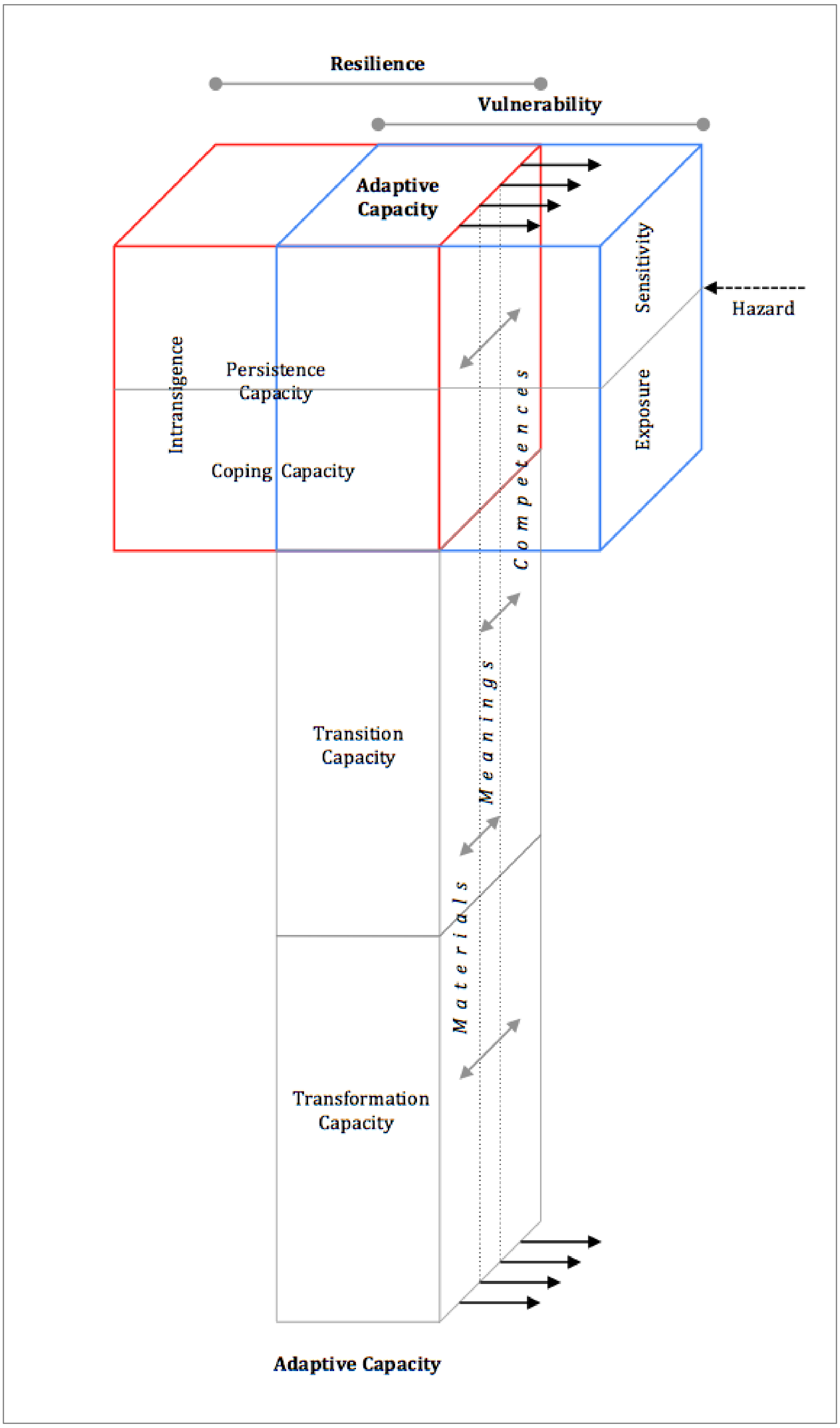


Fig. 7.1. *AdapT*, an integrated vulnerability-resilience conceptual model

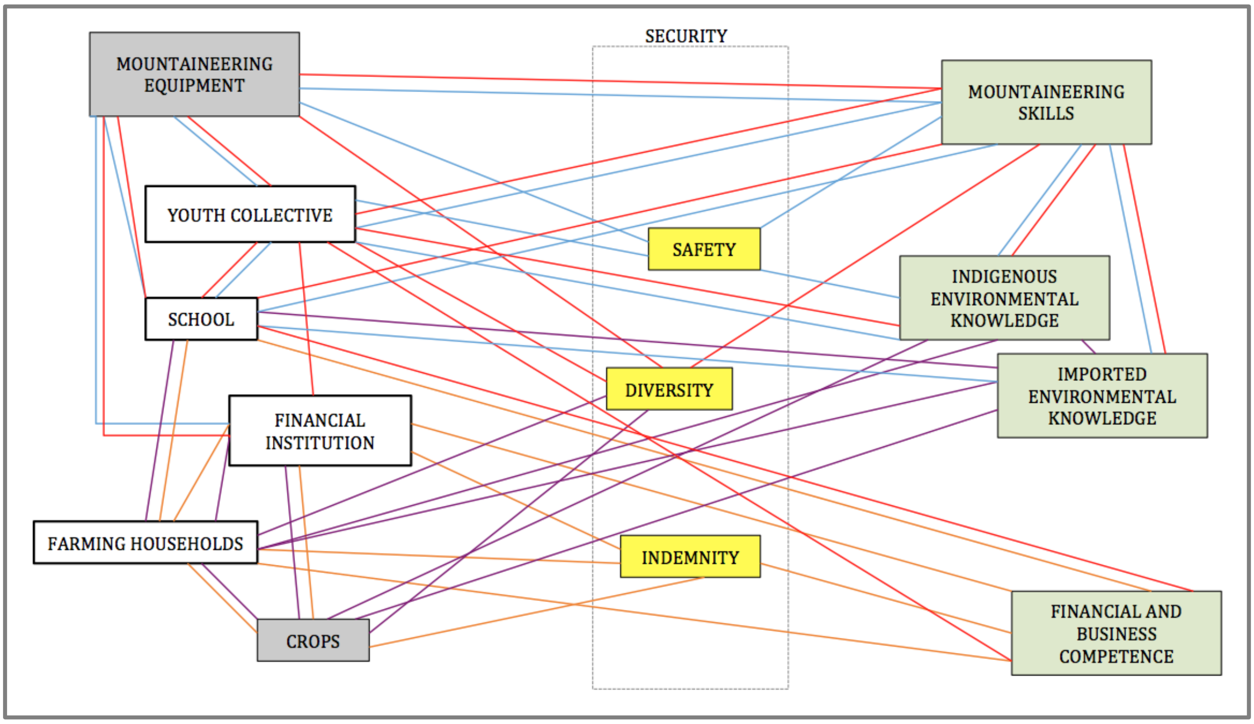


Fig. 7.2. Adaptive capacity represented as the container of a meta-bundle of adaptive practices: An illustrative example from a hypothetical mountain community

Abstracted from the two field-based Himalayan case studies, the figure shows a hypothetical bundle, or rather a bundle of bundles or *meta-bundle* (Shove et al. 2012), of adaptive practices for a poor agrarian community inhabiting a harsh and changing high-mountain environment in the developing world. The interacting *elements* (Shove et al. 2012) that shape these practice bundles while residing in the community's adaptive capacity are represented by boxes of four different colours – grey for *materials*, yellow for *meanings*, pale green for *competences*, and white for institutions. Each institution embodies a bundle of practices, and each of those practices could be zoomed into (see Nicolini 2012) and analysed in terms of interacting materials, meanings and competences. However, at the present scale of analysis, institutions need to be treated as black boxes, just like the three other kinds of elements. The three distinct meanings in the diagram (physical safety, livelihood diversity, and indemnity) are conceptualised as constituents of the broader notion of community security in relation to environmental change and hazards. This demonstrates the possibility of meanings being embedded (nested) within larger meanings.

Interactions between the elements are represented by lines of four different colours, each corresponding to an adaptive practice, or rather an adaptive practice bundle. Many elements are shared by two or more adaptive practice bundles. The four adaptive practice bundles are: *crop insurance* (rust), *crop diversification* (purple), *adventure tourism entrepreneurship* (red), and *community-managed disaster rescue* (blue). Crop insurance indemnifies farming households against financial losses from crop failure caused by environmental extremes, and therefore enhances *persistence capacity*. However, by absorbing environmental shocks and transferring risks in the short term, it might prevent farmers from modifying their farming systems (e.g. making a *transition* to new, potentially more successful crops or farming practices) or giving up farming altogether and trying out something potentially more profitable (*transforming* their livelihoods). Crop diversification, another practice bundle employing farming households and crops as the core elements, reduces risk through livelihood and income diversification; apart from strengthening persistence capacity, it might pave the way for a transition within the farming system. Adventure tourism entrepreneurship, which, in this context, involves mountaineering-based tourism, is potentially transformative in that it may fundamentally alter the "poor agrarian" community. The same mountaineering-related institutions, materials, and competences that contribute to adventure tourism entrepreneurship combine with the notion of physical safety to shape community-managed disaster rescue, a vital system-maintaining practice bundle.

7.2. Operationalising *AdapT*: A practice-based review of adaptive capacity

This section operationalises the *AdapT* model, using its practice-based framing of adaptive capacity as a conceptual instrument for planning an integrated, culturally sound climate change adaptation and disaster risk reduction strategy within the context of the case studies. It does so by revisiting the appraisal of adaptive capacity carried out in Chapter 6 and distilling the discussion under each category – psycho-cultural, social, economic, logistical, and governance-related – into bundles of key practices that aid adaptation. These practice bundles (Shove et al. 2012) represent one of the following for the case study communities: (i) inherent *strengths* that help them maintain or restore their long-term normal state of functioning in the face of hazards (*persistence capacity* in *AdapT*); (ii) existing *opportunities* to make incremental or radical changes that improve their state of functioning in the face of hazards (*transition* or *transformation capacity* in *AdapT*); and (iii) *aspirations* (imagined possibilities as opposed to existing opportunities) towards making radical changes that improve their state of functioning in the face of hazards (*transformation capacity* in *AdapT*). In this way, the communities' strengths, opportunities, and aspirations vis-à-vis adaptation are mapped, representing their psycho-cultural, socio-economic, managerial and governance-related capacities to undertake practices of persistence, transition and transformation, which correspond to the three layers of adaptive capacity in the *AdapT* model (see Table 7.1 below). Since any action strategy essentially comprises a set of practices, this review of the communities' adaptive capacities in a practice-based format is able to act as a direct input into the strategic framework for adaptive action developed in Section 7.3.

The tool employed to execute the above process is an adapted version of SWOT analysis – a common strategic planning procedure that involves recording in a matrix the internal strengths (S) and weaknesses (W) as well as the external opportunities (O) and threats (T) that are expected to support or impede the progress of a social agent (in this case, the two communities) towards a strategic goal (in this case, climate change adaptation and disaster risk reduction; for the only previous application in this context, see Kaul and Thornton 2014). SOA analysis, the variant of SWOT used in this study, excluded weaknesses (W) and threats (T) and incorporated aspirations (A) in response to relatively recent calls for an appreciative approach to strategising – one that replaces the negative, potentially demoralising/stigmatising emphasis on mitigating weaknesses and threats with a positive, potentially uplifting/inspiring focus on building upon strengths while reimagining any gaps as opportunities for improvement or aspirations towards a better future (Srivastava and Cooperrider 1999, Stravos and Sutherland 2003, Stravos et al. 2007, Stravos and Hinrichs 2007, Cooperrider et al. 2008, Stravos 2013). These positive motivational effects and strategic benefits of engaging with the positive aspects of a system (working with what already works) rather than its problems (working on what does not work) are also one of the key reasons why this study examines risk through the adaptive capacity lens rather than by assessing vulnerability (see Engle 2011, Handmer 2003; see also Section 2.2.2).

Table 7.1 presents SOA (strengths, opportunities, aspirations) analysis as a practice-based framework for reviewing the adaptive capacities of both case study communities in a setup that facilitates strategic planning. Extracted from the empirical appraisal of the case study communities' adaptive capacities in Chapter 6, the bundles of key adaptive practices included in the table exemplify capacities for persistence (embodying strengths) and capacities for transition and transformation (embodying opportunities and aspirations). Embedded within these capacities for adaptation (persistence, transition, or transformation) are the elements that shape the above bundles of adaptive practices. The elements include: *materials, competences*, and *meanings* (Shove et al. 2012; see Sections 2.2.2, 7.1, Figs 7.1, 7.2). *Institutions* have been added here as a fourth element. Each institution embodies a bundle of practices, and each of those practices could be zoomed into and analysed in terms of interacting materials, competences, and meanings. However, at the present scale of analysis, institutions are to be treated as black boxes, just like the three other kinds of elements (see also Section 7.1, Fig. 7.2).

Examples of the three kinds of elements (as well as the institutions) that come together to constitute each bundle of practices of persistence/transition/transformation have been provided in the SOA matrix. As represented in the *AdapT* model, these elements of adaptive practices are the stuff that adaptive capacity is made of (see Fig 7.1). Therefore, strengthening a particular element of an adaptive practice contributes to the expansion of adaptive capacity, thereby aiding adaptation and reducing vulnerability and risk. Also, making new links or breaking or repairing existing links among elements of adaptive practices can create new adaptive practices or improve existing ones, thereby aiding adaptation (see also Fig. 7.2).

Table 7.1. SOA* analysis as a practice-based framework for reviewing adaptive capacity and strategising adaptation

Dimension of adaptive capacity	*Examples of key bundles of adaptive practices and their critical elements** from both case study communities*		
	Practices of ***persistence***^ that embody **strengths**	Current practices that present **opportunities** for ***transition***^/***transformation***^	Practices that exemplify long-term **aspirations** towards ***transformation***^
Psycho-cultural	**Traditional non-materialist metaphysics-based psychological coping, including emotional-spiritual self-immunisation against geophysical risk** ***Me*****: *traditional faith-based metaphysical convictions, spiritualities, emotionalities, and moralities that promote psychological detachment from materiality* ***C***: *traditional geomorphically referenced/embodied non-materialist religious/folkloristic knowledge; religious/spiritual training* ***Ma***: *human brains/bodies; religious scriptures, artefacts and mass media items* ***I***: *monasteries/traditional learning institutions*	**Modernisation-influenced materialist psychological engagements with risk, including "rational" behaviours motivated by a sense of material vulnerability and oriented towards practically reducing geophysical risk** ***Me***: *materialist worldviews that promote psychological attachment to physical possessions* ***C***: *materialist environmental knowledge* ***Ma***: *human brains/bodies; modern scientific/worldly educational material and mass media items; material possessions/assets exposed to geohazards* ***I***: *modern learning institutions; government bodies*	
Social	**Traditional kinship/clan-based cooperation and self-organisation** ***C***: *traditional social skills* ***Me***: *shared traditional collectivist values, emotionalities, and moralities* ***Ma***: *shared community assets; common property resources* ***I***: *traditional socio-political/financial groupings/collectives; local self-government bodies (*dzumsá *in ULC,* panchāyat *in UM)*	**Modernisation-driven/disaster-triggered entry of females into local waged employment** ***C***: *modern vocational skills for females (typically not antagonistic to traditionally defined gender roles)* ***Me***: *modern ideas about gender equity; financial pragmatism leading to tradition-bending/defying outlooks on gender roles* ***Ma***: *human labour, financial and real capital, and raw materials enabling the economic activity* ***I***: *women's self-help groups; development NGOs; micro-/small-/medium-scale enterprises*	

Dimension of adaptive capacity	*Examples of key bundles of adaptive practices and their critical elements** from both case study communities*		
	Practices of ***persistence***^ that embody **strengths**	Current practices that present **opportunities** for ***transition***^/***transformation***^	Practices that exemplify long-term **aspirations** towards ***transformation***^
Economic	**Side investment in assets (physical/financial), livelihood resources, and economic activities (vocations/jobs) that have low levels of exposure to geohazards (e.g. by being located outside high-mountain environments or being based indoors)** ***C****: practical knowledge of risk and financial/economic resilience* ***Ma****: assets such as property, livestock, bank savings, precious metal holdings, etc. owned/stored in geophysically safe places* ***Me****: motivation to indemnify the geohazard-exposed household/family against unexpected economic shocks* ***I****: financial institutions (banks, cooperative microfinance bodies); private and state employers*	**Employment-driven mass out-migration (particularly to lowland cities)** ***C****: modern education; vocational skills; employability-related (English) linguistic, financial, and technological competence* ***Ma****: human labour; financial resources for initial forays into urban world; Internet-enabled mobile phones* ***Me****: financial/material ambitions; enterprising attitudes* ***I****: modern learning institutions; private and state employers*	**Development of local entrepreneurship (in tourism, mountain sports, culture, small-scale manufacturing), self-employment, and livelihood diversification through improved access to credit/markets, skill development, and reduced bureaucratic controls** ***C****: modern education; vocational skills; employability-related (English) linguistic, financial/marketing/ technological competence; marketable traditional knowledge/skills (cultural/ecological/mountain-related)* ***Ma****: human labour; capital/credit for setting up enterprises; Internet-enabled mobile phones* ***Me****: financial/material ambitions; enterprising attitudes; inclination to not out-migrate* ***I****: modern learning institutions; financial institutions (banks, cooperative microfinance bodies); supporting government schemes, NGOs, and corporate social responsibility initiatives*
Logistical		**Expansion of state-provided critical infrastructure (especially all-weather telephony, all-weather mountain roads, electricity, and healthcare)** ***C****: administrative/managerial and technical competence in infrastructure creation/delivery; technology* ***Ma****: financial and real capital; human labour* ***Me****: political will and bureaucratic motivation* ***I****: governmental departments/organisations; engineering/construction enterprises*	**Advancement of community-level self-sufficiency in logistical resources required for disaster response** ***C****: local competence in development planning and crisis management; local relief and rescue training* ***Ma****: disaster response equipment; relief material supplies; human labour* ***Me****: aspiration towards local self-reliance* ***I****: local formal self-government bodies (*dzumsá *in ULC,* panchāyat *in UM); informal community self-help groups and collectives*

Dimension of adaptive capacity	*Examples of key bundles of adaptive practices and their critical elements** from both case study communities*		
	Practices of ***persistence***^ that embody **strengths**	Current practices that present **opportunities** for ***transition***^/***transformation***^	Practices that exemplify long-term **aspirations** towards ***transformation***^
Governance-related		**National and provincial-level legislation and planning to support risk reduction and adaptation (inspired by international policy frameworks)** ***C****: bureaucratic and legislative competence in theory and practice of disaster risk reduction, climate change adaptation, and sustainable development; up-to-date knowledge of international policy developments and grassroots-level issues* ***Ma****: financial, academic, and technical capital* ***Me****: political will and bureaucratic motivation* ***I****: governmental and non-governmental research/policy/planning/legal institutions*	**Decentralised risk governance supported by both local and imported knowledges and based on local risk assessments conducted at spatial scales large enough (e.g. 1:5,000 instead of 1:50,000) to be practically useful for hamlet-level adaptive planning** ***C****: local-level (district-, sub-district, and community-level) technical competence in risk assessment and governance, knowledge integration, and spatial planning* ***Ma****: local-level financial, academic, and technical capital (e.g. computers and software)* ***Me****: political/bureaucratic will to devolve risk governance powers and promote community-based environmental stewardship* ***I****: district- and sub-district level governments; village-level self-government bodies (*dzumsá *in ULC,* panchāyat *in UM); informal community self-help groups and collectives; local/regional academic institutions*

*** SOA** stands for *Strengths, Opportunities, Aspirations* (see Section 7.2; Stravos et al. 2007, Stravos and Hinrichs 2007, Stravos and Sutherland 2003, Stravos 2013, Cooperrider et al. 2008).

^ Practices of *persistence*, *transition*, and *transformation* correspond, respectively, to the three levels of adaptation discussed in Pelling (2011) and used to conceptualise the three layers of adaptive capacity in the *AdapT* model (see Section 7.1): adaptation for [system-maintaining] resilience (confined to functional persistence), for transition (more pervasive but incremental change), and for transformation (radical change).

****** *Elements* of practices (Shove et al. 2012; see Section 2.2.2) include: meanings (labelled **Me**), competences (**C**), and materials (**Ma**). Institutions (**I**) have been added here as a fourth element (see Section 7.2).

Cell colours: Light rust cells show adaptive practice bundles and elements that are located (almost) entirely within the community. Light blue cells show adaptive practice bundles and elements that are located (almost) entirely beyond the community and mostly within the purview of the state. White cells show adaptive practice bundles and elements that are located both within and beyond the community. Grey cells indicate no data.

By identifying the *materials* and *competences* involved in the constitution of adaptive practices as some of the substance of adaptive capacity, *AdapT*, as operationalised via the SOA analysis, enables a systematic inventorying of the physical and financial resources, bodies of knowledge, and practical skills – both traditional/local and modern/imported – that are already aiding or are needed to be mobilised for aiding specific community-level adaptive practices on the ground.

By also formally recognising the *meanings* involved in the constitution of adaptive practices as some of the substance of adaptive capacity, the *AdapT*-informed SOA analysis provides a conceptual medium for systematically engaging with the inescapable but commonly overlooked psycho-cultural dimension of adaptation and risk reduction. This makes it possible to use the *AdapT*-based SOA framework to incorporate into practical adaptation agendas such considerations as the behavioural influence of the metaphysical, emotional, spiritual, and moral associations people have with their community and physical environment within the context of their culture.

The above contribution of *AdapT* and the subsequent SOA analysis is important because adaptation strategies that are responsive to the psycho-cultural meanings embedded in a community's practices tend to be socially pertinent and compatible, and therefore perform better on the ground than those that are not (see Bankoff 2004, Ford et al. 2016). In the context of the two case studies, for example, an adaptation strategy that acknowledges, draws upon, and works with the traditional *karma*-based metaphysics and associated understandings of environmental causality is likely to be more socially impactful than one that is oblivious or dismissive of such a powerful influence on the collective psyche. Similarly, an appreciation of the cultural values upon which the communities' practices are built can allow an adaptation strategy that focuses on reinforcing the particular values that serve its purpose and supplanting the ones that do not. For instance, building on the traditional collectivist values of the close-knit communities (a *strength* or source of persistence capacity) can enhance risk-reducing practices that involve cooperation and coordination. At the same time, supporting emerging modern values relating to gender equity and women's right to access paid employment (an *opportunity* or source of transition/transformation capacity) can enhance risk-reducing practices that financially empower women and lessen their economic dependence on men. In addition, providing power-devolving alternatives to the authoritarian values entrenched in the national, provincial, and district-level bureaucracies (an *aspiration* or a source of transformation capacity) can drive new risk-reducing practices that decentralise the governance of risk, allowing the communities to take greater charge of their future in the face of environmental and social change.

Through the process of identifying the key bundles of adaptive practices that exemplify the case study communities' psycho-cultural, socio-economic, and managerial capacities to persist (strengths) and to change (opportunities and aspirations) in the face of climate-related disaster risk, the SOA analysis acts as an instrument for feeding ground-based empirical insights into a strategic plan on adaptation and risk reduction. In this manner, it directly informs the development of a framework for practically aiding climate change adaptation and disaster risk reduction. It is to be noted here that this dissertation is not a practitioner's report seeking to make highly context-specific recommendations for action, but rather an academic project that uses the two case studies as an empirical medium for abstractively developing a broader strategic *framework* or schema that can be applied to similar situations elsewhere. Presented in Section 7.3, this framework is intended for devising holistic, culturally responsive adaptive strategies that can help in managing climate change-related disaster risk at the community level, especially among geographically remote, culturally traditional, and economically developing mountain societies.

Another point to note is that the SOA analysis undertaken above does reflect a community-focused approach to adaptation, but not one that is rooted entirely within the two communities (see Kaul and Thornton 2014). It locates many of the adaptive capacity-constituting elements of adaptive practices well within the communities, but also engages with those portions of adaptive capacity that lie beyond the communities, such as critical infrastructure, planning and law-making, which are all controlled by the geographically distant machinery of the modern state. Overall, it is these externally controlled portions of adaptive capacity that seem to need the most augmentation through practices of transition and transformation, some of which entail transferring political control of risk management to the communities themselves. This aspiration towards more devolved governance is enshrined in the fourth of the four *pillars of adaptive practices* that constitute the strategic framework proposed in the following section. As will be elucidated below, the strategic framework is informed by the SOA analysis' multi-dimensional engagement with adaptive capacity, and ultimately by the underlying practice-based characterisation of adaptive capacity in *AdapT*.

7.3. A holistic strategic framework for adaptation and risk reduction

Presented below is a strategic framework that seeks to operationalise the dissertation's key insights and arguments, and is directed at policymakers and development practitioners. It is intended to guide holistic, community-focused and culturally apt adaptation and risk reduction, particularly in the context of remote, traditional societies facing climate change-related mountain geohazards in the developing world. The guidance it offers is grounded in the practice-based review of adaptive capacity undertaken in Table 7.1, and the ideas and insights underpinning that review in Sections 7.1 and 7.2, as well as the extensive case study-based discussion of risk throughout Chapters 4-6.

The proposed framework comprises four pillars, each of which contains bundles of adaptive practices that are recommended for enhancing the capacities to *understand*, *communicate*, operationally *tackle*, and *govern* risk at the community level. The pillars of understanding and communication draw extensively upon the psycho-cultural dimension of adaptive capacity (as presented in the SOA analysis). They underline, in particular, the crucial role of *meanings* (as conceptualised in *AdapT,* after Shove et al. 2012) in shaping adaptive practices and ultimately reducing risk. The pillar of operational tackling mainly reflects the socio-economic and logistical dimensions of adaptive capacity in the SOA analysis, relying heavily on *materials* and *competences* but also not overlooking *meanings* (*AdapT*). The pillar of governance mirrors the governance-related dimension of adaptive capacity in the SOA analysis, focusing on *competences* but also considering *meanings* and *materials* (*AdapT*). Together, the four pillars are expected to comprehensively support the expansion of adaptive capacity and the resultant reduction of risk. The particular emphasis on the *meanings* embedded within adaptive practices arguably pushes the boundaries of conventional (*material-* and *competence*-focused) adaptation, making it more cognisant of behaviourally potent psycho-cultural realities.

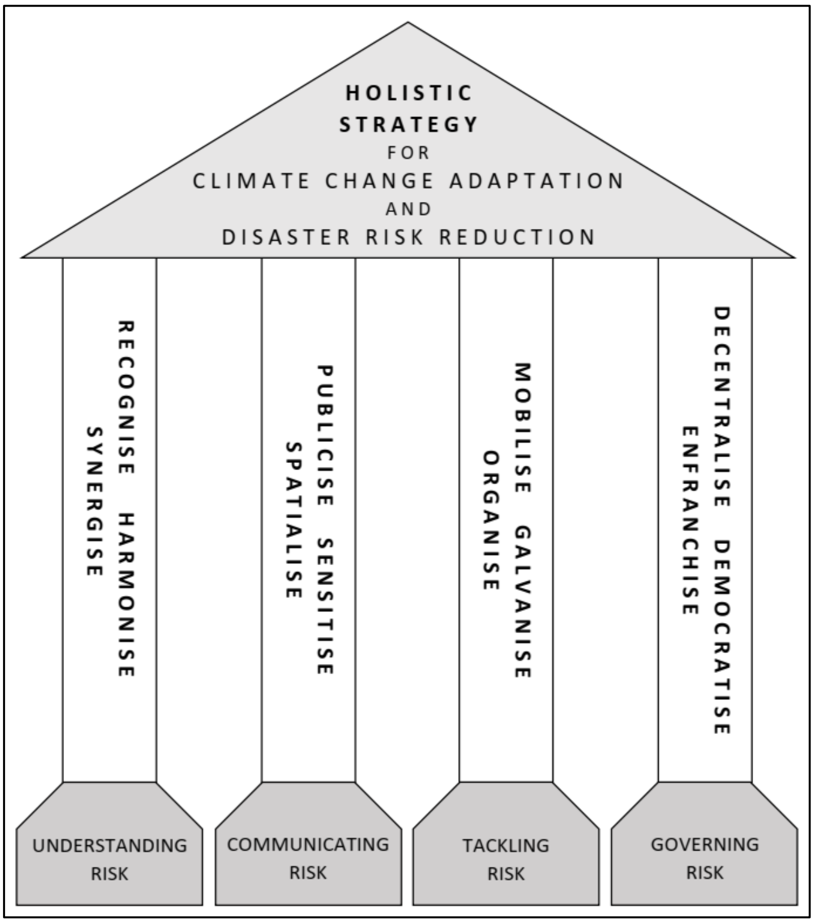


Fig. 7.3. A four-pillared strategic framework for holistic adaptation and risk reduction

Understanding risk: recognise, harmonise, and synergise

This first pillar of adaptive practices relates to *meaning*- and *competence*-expanding psycho-cultural and epistemic interventions aimed at reducing risk by *understanding* it more comprehensively. This involves, firstly, the practice of *recognising* and appreciating all of the many ways of knowing about environmental dynamics, ranging from numerical models based on modern/Western materialist science to folkloristic expressions based on traditional/indigenous non-materialist metaphysics. To enable this, each form of knowledge needs to be documented and presented to holders of other forms of knowledge in formats that are accessible to them. For example, a landslide susceptibility map (*material* with embodied *meanings* and *competences*) prepared by a geoscientist may need to be converted into a three-dimensional visualisation with detailed spatial references to local religious legends (of spirits, deities, etc.) before a traditional community can use it efficaciously. Similarly, geographically referenced religious legends relating to local-scale nuances of geological processes may need to be decoded by a holder of both traditional and modern scientific knowledges before a geoscientist can use them to some effect. That is where the practice of interpretively *harmonising* (albeit not synthesising or merging into one entity) multiple perspectives comes in, helping to make those perspectives mutually intelligible and identify the epistemic convergences and divergences between them. The practice of *synergising* follows, which entails building on the identified epistemic convergences so as to make the different ways of knowing functionally complement and work with each other towards the goal of risk reduction. Harmonising and synergising are exemplified by the entirety of the empirical work undertaken in Chapters 4 and 5, which positions ontologically disparate traditional/indigenous and modern/Western scientific understandings of environmental risk alongside each other, enabling the methodological rigour and precision of abstractively developed Western geoscience to complement the context-specificity and experiential groundedness of situationally developed local geographical knowledges.

Since knowing about risk is the foundational first step towards managing it, this pillar is the one upon which the strength of the other three depends. It is in this context that the adaptive practices enshrined within this pillar represent the essential purpose of the current dissertation – to advance adaptation by appreciating, on their own terms, different knowledges and understandings of risk.

Communicating risk: publicise, sensitise, and spatialise

Closely related to the first pillar of understanding is the second pillar of *communication*, which also relies on *meaning*- and *competence*-expanding interventions. Once risk has been holistically understood through the practices of recognition, harmonisation and synergisation, it needs to be effectively communicated. This requires continued attention to the specifics of knowledge, understanding, and lived experience in the communities and institutions concerned. The first step in that direction is to *publicise* risk – not only among the communities facing it, but also among external agencies that might support risk reduction both financially and technically.

In the context of communities, the practice of publicising risk may focus on *sensitising* local authorities and households to such ideas (*meanings*) as minimising physical exposure to hazards (e.g. by not erecting new buildings close to a flash flood-susceptible river or immediately downslope of a previous landslide) and financially indemnifying human lives, property, livestock, crops against hazards (e.g. through insurance schemes offered by banks and alternative financial *institutions* such as post offices, which have a far more extensive network than banks in the two case study regions). The modes of publicity (comprising *materials* and *competences*) for the above ideas (*meanings*) may include physical media, such as pamphlets, posters, newspaper advertisements, hoardings, public service messages painted on walls and public transport vehicles, and folk theatre-based campaigns (a practice in itself, involving materials as well as *competences* and *meanings*), as well as electronic media, including radio, television, and mobile phone-based messaging and social media platforms (e.g. WhatsApp and Facebook, which are popular throughout the two case study regions).

In the context of potential external aid providers, which range from individual philanthropists in the urban/developed world to international development and environment agencies, *sensitisation* may draw upon ideas (*meanings*) such as climate justice and ethics (e.g. the morally evocative assertion that the climate change-related risks being faced by remote, unindustrialised low-consumption societies in the Global South have been inflicted upon them by high-consumption societies, especially those of the Global North). Media (comprising *materials* and *competences*) for publicity practices targeting aid providers may include practitioners' reports, policy briefs, journalistic articles (print and online), short online campaign videos, and longer broadcast documentary films.

For risk communication to be practically useful in the context of planning adaptation on the ground, it needs to take place in formats that provide a sense of *spatiality* – of how environmental hazards and human vulnerabilities interact over space. Owing to their ability to spatially contextualise risk, visual media such as maps, photographs and video content may be particularly effective in communicating and ultimately reducing risk. In order for maps to practically aid risk reduction, it is necessary for them to be prepared at appropriate spatial scales (a matter concerning *competences*). For example, in the context of the two case studies, hazard and vulnerability maps prepared by governmental agencies are generally not larger-scaled than 1:50,000, so they depict entire communities as single dots. This makes those maps useful only for provincial-scale adaptive planning. Community-scale risk mapping (at scales ranging from 1:20,000 to 1:5,000 or larger) may be possible only if investments are made in augmenting *materials* and *competences* such as very high-resolution environmental datasets procured from remote sensing agencies and adequate ground-level terrain data and household-level social data collected by external researchers in partnership with local community members.

Tackling risk: mobilise, galvanise, and organise

The third pillar of the framework contains adaptive practices that directly enable risk-reducing interventions on the ground. These practices entail, first of all, the *mobilisation* or marshalling of *materials*, *competences*, and *meanings* that have the potential to serve a particular risk reduction goal. Once all the resources are in place, they need to be *galvanised* into action by activating interactional links among them that shape the desired risk-reducing practices. To sustain those desired risk-reducing practices over the long run, the practitioners may *organise* themselves into communities of practice, within which the practices may be iteratively refined or even redefined (Wenger 1998). An illustrative example of the above, extracted from the empirical work on the economic dimension of adaptive capacity in Section 6.2.2, is discussed below. It relates to a women's co-operative weaving movement that was initiated by a few members of the Upper Mandākinī (UM) community in collaboration with an external NGO in the immediate aftermath of the June 2013 debris flow disaster.

The 2013 disaster had killed a considerable proportion of the UM community's breadwinning males (who had been working at geophysically hazardous locations on the local pilgrimage circuit), thereby suddenly rendering their dependants (especially females, for whom waged work was traditionally taboo) financially and socio-economically vulnerable. The crisis had led to the need for quickly developing a new socio-culturally appropriate means of livelihood for women, especially those widowed during the disaster. This need was met when a few enterprising community members joined hands with an external NGO that had two decades of prior experience in co-operative weaving and handcrafting with rural mountain women in the same province. The NGO assisted the community in setting up a small-scale women's weaving enterprise by providing *materials* in the form of financial and physical capital (e.g. worksheds, spinning frames, handlooms) and raw materials (e.g. wool and other fibres) as well as *competences* in the form of technical training, designs, knowledge and practical skills relating to credit and market access, etc. It also strengthened emerging *meanings*, including socio-economically transformative modern values that encourage women's participation in remunerative employment (as opposed to their traditional confinement to unpaid work such as household chores, livestock rearing, and firewood/fodder collection). These values were made socio-culturally compatible through the provision of all-female work environments very near the women's homes as well as the projection of the enterprise as a means for *revitalising* (Thornton and Manasfi 2010) the familiar, morally well-regarded, and traditionally female-dominated practice of weaving. Once all of the above resources were *mobilised*, the initial commercial orders and revenue inflows that the enterprise received (with some support via the founding NGO's pre-existing business network) *galvanised* the enterprise into action, routinising and iteratively streamlining the interactions among the above materials, meanings and competences to firmly establish the bundle of practices embodied by the weaving enterprise. As more orders flowed in over the following two years, the enterprise became financially self-sustaining and expanded its scale of operation by *organising* women in a number of villages into commercial weaving communities that now function semi-autonomously under the identity-providing umbrella of the enterprise. The emergence of many well-organised communities of weavers around the original weaving enterprise has now turned it into a hundreds-strong region-wide movement for women's economic empowerment, which is augmenting local communities' adaptive capacities, increasing their resilience, and reducing their vulnerability in the face of climate change-related geohazards. Within the context of the two case studies, the practices of mobilisation, galvanisation, and organisation could similarly enhance adaptive capacity, for example, by aiding disaster response preparedness or local entrepreneurship development in such fields as adventure/mountain sports, eco-tourism, and traditional arts.

Governing risk: decentralise, democratise, and enfranchise

The adaptive practices contained in the fourth and final pillar of the strategic framework relate to the governance of risk. The practice of *decentralisation* involves the transfer of adaptive planning and risk management powers from national- and provincial-level governments to upwardly accountable local administrative authorities (district- and sub-district-level governments in the case study regions) as well as downwardly accountable elected village-level self-government bodies (*dzumsá* and *panchayat* in the case study regions) and more informal community-level collectives (see Crook and Manor 1998, Agrawal and Ribot 1999, Ribot 2002, Larson 2005). It enhances community-level adaptive capacity by increasing local participation in, and control over, environmental planning and decision-making, thereby *democratising* the governance of environmental risk and *enfranchising* or empowering conventionally marginalised traditional/indigenous knowledges and perspectives (see Crook and Manor 1998, Ribot 2002). Democratisation and enfranchisement play a vital role in politically and institutionally enabling the actual utilisation of local knowledge for adaptation and risk reduction, as opposed to simply a practically inconsequential "appreciation" of it (Xu and Grumbine 2014).

Apart from enriching official adaptation strategies with local *competences* and *meanings* such as context-specific experiential knowledges and culturally rooted understandings of risk, the practices of decentralisation/democratisation/enfranchisement may equip local communities with improved access to externally sourced adaptive capacity-enhancing *competences* and *materials*, such as information technology skills, management training, computer hardware and software provided by governmental or non-governmental development agencies as part of capacity building programmes.

Adaptation strategies involving the devolution of risk governance powers to local-level actors would be particularly beneficial to developing-world rural communities whose geographical remoteness from the state makes any significant economic or logistical dependencies on the state a key source of vulnerability for them. The two high-mountain case study communities are classic examples of this situation, especially in respect of their non-existent, limited or unreliable motorised transport and telecommunication links with administrative centres (see Section 6.2.3). It is critically important for such remote, and often inaccessible, communities to have a certain degree of logistical self-sufficiency and managerial autonomy vis-à-vis adaptation and risk reduction.

The four-pillared strategic framework proposed above has a fairly simple design, yet it is responsive to the multi-dimensionality of human vulnerability/resilience and adaptation in face of environmental hazards. The distinctiveness of the framework lies in its ability to provide a medium for practically engaging with the foundational but neglected psycho-cultural dimension of adaptive capacity in conjunction with the more commonly examined socio-economic and managerial aspects. This ultimately contributes towards making climate change adaptation and disaster risk reduction more responsive to the local cultural contexts in which they are undertaken.

7.4. Conclusion

This chapter marks the culmination of the empirical work undertaken in Chapters 4-6 towards developing holistic, culturally responsive understandings of climate change-related mountain geohazards and associated human adaptive capacities. It takes the project of understanding risk a step further by exploring ways to practically enhance community-level adaptive capacities and reduce risk in holistic, psycho-culturally engaged ways. In that process, it proposes a practice-based conceptual model of adaptive capacity, which it operationalises in multi-dimensionally reviewing the case study communities' adaptive capabilities, possibilities, and aspirations. Drawing upon that strategic planning-oriented review of the communities' adaptive potential as well as the underlying empirical work on risk, the chapter abstractively devises a strategic framework for holistic community-level climate change adaptation and disaster risk reduction, particularly in the context of remote, traditional mountain societies in the Global South. This strategic framework for understanding, communicating, operationally tackling, and governing climate change-related disaster risk provides a means for practically engaging with adaptive capacity in all its dimensions, including its psycho-cultural bedrock.

8. Conclusion

This interdisciplinary dissertation set out to holistically understand human engagement with the severe risks arising from hydrometeorologically triggered mountain geohazards in the wake of recent climatic change and also contemporaneous processes of social change. Focusing on remote rural communities in two monsoon-affected river basins in the Indian High Himalaya, the study used methods such as extended ethnographic fieldwork, qualitative local-scale geomorphological observations, and quantitative hydroclimatological analyses to answer the following research questions within an integrative place-based case study framework:

iv. How do local understandings (traditional or otherwise) of climatic change, hydrometeorological extremes, and associated high-mountain geohazards compare with regional- and local-scale Western scientific understandings?

v. How do local communities construct and appraise their own adaptive capacities in the face of risks from climate change-related high-mountain geohazards and concurrent social change?

vi. How can community-level climate change adaptation and disaster reduction practically benefit from holistic, grounded, and culturally responsive engagements with risk?

In answering the first research question, the dissertation placed ontologically disparate local/traditional and Western/modern scientific understandings of climatic change-related high-mountain geohazards into the context of each other, allowing the unique insights offered by each to be appreciated against the backdrop of the other. Chapter 4 compared local narratives of climatic change and hydrometeorological extremes with inferences derived from instrumental temperature and precipitation observations as well as climate model projections, positioning quantitative climatological data in relation to culture and qualitative ethnographic data in relation to climatology. It found the social and climatological insights to be in broad agreement that both communities are witnessing, overall, a climatic tendency towards higher temperatures, lower snowfall, and greater extremes in monsoon precipitation – a set of conditions that can be expected to intensify the combined hazard of thermally induced geomorphic destabilisation, deglaciation-linked meltwater accumulation, and rainfall-triggered landsliding and flash flooding in high-mountain environments. The implications of these changes for each case study community in terms of disaster risk were examined in Chapter 5.

Chapter 5 used shared geographies to integrate the seemingly irreconcilable geoscientific and indigenous knowledges of hydrometeorologically triggered geohazards such as glacial lake outburst floods and debris flows, both spatially – through geomorphological maps and sketches – and conceptually – through physical and metaphysical models of landscape processes. The integrative project was undertaken in the pluralist spirit of "two-eyed seeing" (Bartlett, Marshall and Marshall 2007, 2012). This favoured a mutually enriching co-existence of fundamentally different or even contradictory understandings over a contrived fusion or race-for-dominance between perspectives to arrive at a singular "correct" view (Ford et al. 2016, Martin

2012). The analysis found, for example, that while Western geoscientific causation operates within the realm of physical reality, local/traditional ontologies of geohazards transcend material processes and use moral consciousness as the causal medium through which non-physical "impulses" travel from a physical cause to its physical effect. Despite appreciating this intrinsic incongruence between the two worldviews, the analysis positioned them alongside each other, enabling the methodological rigour and precision of abstractively developed Western geoscience to complement the context-specificity and experiential groundedness of situationally developed local geographical knowledges. Western scientific and local knowledge-based hazard appraisals were systematically compared, but to initiate a collaborative epistemic dialogue rather than to pit quantitative geoscientific models of landscape dynamics against qualitative folkloristic models that lend geological form and spatiality to traditional metaphysical convictions, spiritualities, moralities, and emotionalities associated with geohazards operating within a certain social change context. This generated a rich, multi-dimensional understanding of geohazards, which is both scientifically well-founded and culturally situated.

Remarkably, Western science and local knowledges in the two case study communities were found to understand the *physicality* of high-mountain geomorphic processes in very similar ways. This was seen to lead them to make similar inferences about the magnitude of a given geohazard. Moreover, the nuanced ground-level observations of regional- and local-scale geomorphic peculiarities provided by local experiential knowledge were found to usefully complement the quantitatively sophisticated simulation models of geohazards offered by Western science. Both knowledge systems were also observed to agree that a warming climate with increasingly more extreme summer precipitation and declining snowfall is exacerbating high-mountain geohazards such as glacial lake outburst floods and debris flows. They were found to even make similar observations on the geohazard-amplifying effects of climatic change on geomorphic processes. This showed that the two knowledge systems might be able to work together towards risk assessment and management. However, traditional knowledges in both communities were found to still conceive of hazard-shaping and hazard-triggering geophysical processes (meteorological, climatic, geomorphic, and hydrologic) as mere physical expressions of an invisible anthropogenically influenced machinery that administers moral justice in accordance with the shared Hindu-Buddhist metaphysical doctrine of *karma*. This was seen to make traditional knowledge-based appraisals of the likelihood of geohazard activation dependent on the physically indeterminable need for a morally purgative, spiritually revelatory catastrophe, and therefore incomparable with geoscientific risk assessments. Nonetheless, the karmic control over geophysical (including atmospheric) processes was seen to make traditional knowledge holders attribute a hydrometeorologically triggered disaster to cumulative human vice resulting from excessive collective material consumption. Despite its fundamentally different underlying causal mechanism, this *moral* explanation is functionally compatible with the *physical* understanding of Western science that anthropogenic greenhouse gas emissions caused by global-scale human consumption contribute to geohazard-activating hydrometeorological extremes. It may be concluded, therefore, that Western scientific and local epistemologies of geohazards in the two study regions are not entirely irreconcilable.

A key practical outcome of the epistemological pluralism demonstrated in Chapters 4 and 5 is that it enriches earth science-based assessments of climate change and associated geohazards with ethnographically robust emic perspectives on environmental dynamics, providing external development practitioners, planners and policymakers with a genuine sense of lived experiences of change and extremes in the physical environment. Through their deep engagement with the neglected but behaviourally potent psycho-cultural and religio-spiritual dimensions of human-environment relationships, these chapters advance a holistic epistemology of extremes and hazards in changing environments. This can aid in developing more culturally compatible, and therefore potentially more efficacious, strategies for climate change adaptation and disaster risk reduction among remote, traditional high-mountain societies in the Global South. This purpose was pursued in Chapter 7 as part of answering the third research question of the study. However, prior to that, Chapter 6 developed the implications of the pluralistic epistemology of hazards for understanding adaptive capacity.

In addressing the second research question about communities' constructions and appraisals of their own adaptive capacities, Chapter 6 opened with an analysis of rich ethnographic data from the two case studies, demonstrating the behavioural potency of deep-seated metaphysical convictions, moralities, and emotionalities vis-à-vis traditional communities' engagements with environmental risk. By that means, it underlined the critical need for emically examining culturally rooted mass-psychological phenomena as part of adaptive capacity assessments, especially in the context of indigenous societies interacting with extreme geophysical environments. While drawing the reader's attention to the above psycho-cultural factors as a neglected but ineluctable dimension of adaptive capacity, the chapter also acknowledged that practically efficacious, livelihood-focused adaptive strategies cannot be developed without adequately engaging with tangible (and therefore conventionally addressed) socio-economic and managerial issues. The "worldly" aspects of the largely emic appraisal of adaptive capacity encompassed such factors as social structures and relationships, economic assets and opportunities, logistical resources and critical infrastructure, and governmental planning and risk governance machineries.

The ethnographic engagement with the case study communities' constructions of their own adaptive capacities found both communities to be psycho-culturally resilient in terms of the role of their traditional Buddhist/Hindu metaphysical beliefs in enabling a kind of emotional-spiritual self-immunisation against environmental and concurrent social risks. It also found the communities' social capital, especially high levels of clan-based cohesiveness and cooperativeness, to be contributing significantly to their inherent adaptive capacities. Although the analysis did not focus on adaptive capacity differentials within the communities, it did find that in the Western Himalayan Upper Mandākinī Valley community, non-priestly-caste immigrant manual workers from non-native ethnic groups tend to be more exposed to geohazards than the rest of the community, while also holding significantly smaller adaptive capacities in terms of social support and economic assets. Besides, due to gendered social roles, most females in both communities were seen to be financially dependent on male breadwinners, thereby possessing smaller socio-economic adaptive capacities than males. However, men were seen to often be more exposed to geohazards due to their more outdoor-based occupations.

The economic component of both communities' existing adaptive capacities was emically found to be embodied largely by their own autonomous adaptive practices such as out-migration in search of physically and financially secure urban employment as well as long-term transitions to financial investments, livelihood resources, and economic activities that are significantly less exposed to geohazards. These practices were found to be responses not only to environmental risks but also to the livelihood risks that are constantly emerging from the interactions of purely environmental risks with concurrent socio-economic changes such as rapid shifts from traditional economic self-sufficiency to modernisation-induced dependencies on the global market.

State-driven economic support measures such as improving access to credit for livelihood diversification and local entrepreneurship development were found to have a long way to go in enhancing the communities' adaptive capacities. It was observed that the state also has much to do in respect of improving the remote communities' access to critical infrastructure (especially healthcare and rainstorm-ready transport and telecommunication systems); equipping them with key logistical resources for disaster response; enhancing their participation and enfranchisement in adaptive planning and risk governance processes; and tackling wider administrative issues such as poor inter-departmental coordination, low levels of bureaucratic efficiency and accountability, and limited devolution of powers to village-level self-government bodies. Notably, owing to modernisation-induced economic self-insufficiency as well as financial, administrative, and political dependencies on the somewhat centralising state, a significant portion of local adaptive capacity was found to lie beyond the communities themselves. Due to the geographical remoteness of the communities, this was observed to be posing a particular challenge for adaptation on the ground.

Beyond its response to the second research question, Chapter 6 provided an insight into the profound multi-dimensionality of adaptive capacity. It showed that a full assessment of adaptive capacity necessitates working with multiple, intrinsically different kinds of knowledge and understanding, and then finding a way to meaningfully integrate them so that they may benefit adaptive practices on the ground. Chapter 7 developed an integrative framework that drew upon ideas from practice theory to systematically synopsise the extended appraisal of adaptive capacity undertaken in Chapter 6. It did so with a view to answering the third and final research question, thereby making the dissertation's analysis more usable and transferable in terms of the development of a strategic schema for climate change adaptation and disaster risk reduction.

Chapter 7 marked the culmination of the empirical work undertaken in Chapters 4-6 towards developing holistic, culturally responsive understandings of climate change-related mountain geohazards and associated human adaptive capacities. It took the project of understanding risk a step further by exploring ways to practically enhance community-level adaptive capacities and reduce risk in holistic, psycho-culturally engaged ways. In that process, it proposed *AdapT*, a practice-based conceptual model of adaptive capacity, which it operationalised in multi-dimensionally reviewing the case study communities' adaptive strengths, opportunities, and aspirations. Drawing upon that strategic planning-oriented review of the communities' adaptive potential as well as the underlying empirical work on risk, the chapter abstractively devised a strategic framework for holistic community-level climate change adaptation and disaster risk reduction, particularly in the context of remote, traditional mountain societies in the Global South. This four-pillared strategic framework for understanding, communicating, operationally tackling, and governing climate change-related disaster risk provides a means for practically engaging with adaptive capacity in all its dimensions, including its psycho-cultural bedrock. Thus, it addresses the final research question about how community-level climate change adaptation and disaster reduction might practically benefit from holistic, grounded, and culturally responsive engagements with risk. In this way, the framework can be seen to embody the dissertation's practical recommendations (see Section 7.3).

The dissertation's fundamental contribution to knowledge lies in its endeavour to develop such an understanding of adaptation to climate change-related disaster risk as is able to integrate different knowledges without reducing them, facilitating identification of points of contact while not seeking to diminish fundamental differences. This has clear significance as it becomes increasingly apparent that the kinds of hazards researched are set to become substantially more prevalent.

The above offering of the dissertation is philosophically reflected in its integrative methodology, which draws together multiple academic disciplines and the diverse ontological stances, epistemic perspectives, and research methods that come with them. This means, for example, that inherently realist and positivist quantitative analyses offered by Climatology and Geomorphology are embraced concurrently with constructivist and interpretivist qualitative ethnographies offered by Cultural Anthropology. Compounding this methodological multiplicity are epistemological collaborations between modern/Western scientific and traditional/local knowledge systems, between the conceptual paradigms of vulnerability and resilience, and between the practical frameworks of climate change adaptation and disaster risk reduction. The tenability of this rich medley may be challenged on the grounds that it attempts to reconcile intrinsically irreconcilable ontologies and epistemologies. However, the reconciliation it offers is a pluralist one in that its ambition is not to negotiate a compromise between disparate perspectives, but rather to approach the research problem from multiple coexistent standpoints, each of which adds value to the overall understanding of the problem (see Martin 2012). Arguably, this epistemological pluralism presents a highly pragmatic approach to the complex challenge of comprehensively and multi-dimensionally understanding human-environment interactions in the context of climate change-related geophysical risks (see Curtis and Oven 2012, Lane et al. 2011, Mazzocchi 2006, Kaul and Thornton 2014, Ford et al. 2016).

The dissertation's philosophical commitment to disciplinary and epistemic plurality also reflects and celebrates the author's own distinctive positionality as a researcher/observer – both in terms of his academic position within the fundamentally interdisciplinary "discipline" of Geography and a cultural background with a metaphysical heritage that straddles the divide between modern materialist urban/Western societies and traditional eco-spiritualist/mysticist rural Himalayan societies. The place-based empirical work undertaken as part of the Himalayan case studies is indeed an expression of the author's long-cultivated aspiration to build such holistic, grounded, and practically useful understandings of human-environment relationships as are able to transcend the epistemic discontinuities and barriers that prevent free flows of knowledge and insight between diverse academic disciplines and cultures.

References

Adger WN (2003) Social capital, collective action, and adaptation to climate change. Economic Geography 79:387-404

Adger WN (2006) Vulnerability. Global Environmental Change 16:268-281

Adger WN, Agrawala S, Mirza MMQ, Conde C, O'Brien K, Pulhin J, Pulwarty R, Smit B, Takahashi K (2007) Assessment of adaptation practices, options, constraints and capacity. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, and Hanson CE (eds) Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 717-743

Aggarwal S, Rai SC, Thakur PK, Emmer A (2017) Inventory and recently increasing GLOF susceptibility of glacial lakes in Sikkim, Eastern Himalaya. Geomorphology 295:39-54

Agrawal A, Ribot J (1999) Accountability in decentralization: a framework with South Asian and West African environmental cases. The Journal of Developing Areas 33:473-502

Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F (2005) Global health impacts of floods: epidemiologic evidence. Epidemiologic Reviews 27:36-46

Ahmed B, Sammonds P, Saville NM, Le Masson V, Suri K, Bhat GM, Hakhoo N, Jolden T, Hussain G, Wangmo K, Thusu B (2019) Indigenous mountain people's risk perception to environmental hazards in border conflict areas. International Journal of Disaster Risk Reduction [e-publication ahead of print, doi: 10.1016/j.ijdrr.2019.01.002]

Aldrich DP, Meyer MA (2014) Social capital and community resilience. American Behavioral Scientist 59:245-269

Alean J (1985) Ice avalanches: some empirical information about their formation and reach. Journal of Glaciology 31:324-333

Aleotti P (2004) A warning system for rainfall-induced shallow failures. Engineering Geology 73:247-265

Alexander C, Bynum N, Johnson E, King U, Mustonen T, Neofotis P, Oettlé N, Rosenzweig C, Sakakibara C, Shadrin V, Vicarelli M, Waterhouse J, Weeks B (2011) Linking indigenous and scientific knowledge of climate change. BioScience 61:477-484

Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Rupa Kumar K, Revadekar J, Griffiths G, Vincent L, Stephenson DB, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL (2006) Global observed changes in daily climatic extremes of temperature and precipitation. Journal of Geophysical Research 111:D05109

Alfirdaus LK (2014) Disaster and discrimination: the ethnic Chinese minority in Padang in the aftermath of the September 2009 earthquake. Sojourn: Journal of Social Issues in Southeast Asia 29:159-183

Allen MR, Ingram WJ (2002) Constraints on the future changes in climate and the hydrological cycle. Nature 419:224–232

Allen SK, Rastner P, Arora M, Huggel C, Stoffel M (2016) Lake outburst and debris flow disaster at Kedarnath, June 2013: hydrometeorological triggering and topographic predisposition. Landslides 13:1479-1491

Archer DR, Fowler HJ (2004) Spatial and temporal variations in precipitation in the Upper Indus basin, global teleconnections and hydrological implications. Hydrology and Earth System Sciences 8:47-61

Atkinson P, Hammersley M (1994) Ethnography and participant observation. In: Denzin NK, Lincoln YS (eds) Handbook of qualitative research. SAGE Publications, Thousand Oaks, pp 248-261

Au SWC (1993) Rainfall and slope failure in Hong Kong. Engineering Geology 36:141-147

Bacchini M, Zannoni A (2003) Relations between rainfall and triggering of debris-flow: a case study of Cancia (Dolomites, Northeastern Italy). Natural Hazards and Earth System Sciences 3:71-79

Bachri S, Stötter J, Monreal M, Sartohadi J (2015) The calamity of eruptions, or an eruption of benefits? Mt. Bromo human-volcano system a case study of an open-risk perception. Natural Hazards and Earth System Sciences 15:277-290

Bajracharya SR, Mool PK, Shrestha BR (2007) Impact of climate change on Himalayan glaciers and glacial lakes: case studies on GLOF and associated hazards in Nepal and Bhutan. ICIMOD, Kathmandu, 119 pp

Bal PK, Ramachandran A, Palanivelu K, Thirumurugan P, Geetha R, Bhaskaran B (2016) Climate change projections over India by a downscaling approach using PRECIS. Asia-Pacific Journal of Atmospheric Sciences 52:353-369

Bankoff G (2004) In the eye of the storm: the social construction of the forces of nature and the climatic and seismic construction of God in the Philippines. Journal of Southeast Asian Studies 35:91-111

Barnard PL, Owen LA, Sharma MC, Finkel RC (2001) Natural and human-induced landsliding in the Garhwal Himalaya of northern India. Geomorphology 40: 21-35

Barnes J, Dove M, Lahsen M, Mathews A, McElwee P, McIntosh R, Moore F, O'Reilly J, Orlove B, Puri R, Weiss H, Yager K (2013) Contribution of anthropology to the study of climate change. Nature Climate Change 3:541-544

Bartlett CM (2011) Integrative science/Toqwa'tu'kl kijitaqnn: the story of our journey in bringing together Indigenous and Western scientific knowledges. In: Bernard T, Rosenmeier LM, Farrell SL (eds.) Ta'N Wetapeksi'k: understanding where we come from. Eastern Woodland Print Communications, Truro, pp 179-186

Bartlett C, Marshall M, Marshall A (2007) Integrative science: enabling concepts within a journey guided by trees holding hands and two-eyed seeing. Two-Eyed Seeing Knowledge Sharing Series, Manuscript No. 1, Institute for Integrative Science and Health, Cape Breton University, Sydney, Nova Scotia, Canada

Bartlett C, Marshall M, Marshall A (2012) Two-eyed seeing and other lessons learned within a co-learning journey of bringing together indigenous and mainstream knowledges and ways of knowing. Journal of Environmental Studies and Sciences 2:331-340

Bartlett C, Marshall M, Marshall A, Iwama M (2015) Integrative science and two-eyed seeing: enriching the discussion framework for healthy communities. In: Hallstrom LK, Guehlstorf NP, Parkes MW (eds) Ecosystems, society and health: pathways through diversity, convergence and integration. McGill-Queen's University Press, Montreal, pp 280-326

Berg P, Haerter JO (2013) Unexpected increase in precipitation intensity with temperature – a result of mixing precipitation types? Atmospheric Research 119:56-61

Berg P, Moseley C, Haerter JO (2013) Strong increase in convective precipitation in response to higher temperatures. Nature Geoscience 6:181-185

Berkes F, Colding J, Folke C (2000) Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10:1251-1262

Bhambri R, Bolch T, Chaujar RK, Kulshreshtha, SC (2011) Glacier changes in the Garhwal Himalaya, India, from 1968 to 2006 based on remote sensing. Journal of Glaciology 57:543-556

Bhambri R, Mehta M, Dobhal DP, Gupta AK, Pratap B, Kesarwani K, Verma A (2016) Devastation in the Kedarnath (Mandakini) Valley, Garhwal Himalaya, during 16-17 June 2013: a remote sensing and ground-based assessment. Natural Hazards 80:1801-1822

Bhandari RK, Senanayake KS, Thayalan N (1991) Pitfalls in the prediction on landslide through rainfall data. In: Bell DH (ed) Landslides. 2nd edition. AA Balkema, Rotterdam, pp 887-890

Birkmann J (ed) (2006) Measuring vulnerability to natural hazards – towards disaster resilient societies. United Nations University Press, Tokyo

Birkmann J, Cardona OD, Carreño ML, Barbat AH, Pelling M, Schneiderbauer S, Kienberger S, Keiler M, Alexander D, Zeil P, Welle T (2013) Framing vulnerability, risk and societal responses: the MOVE framework. Natural Hazards 67:193-211

Birkmann J, von Teichman K (2010) Integrating disaster risk reduction and climate change adaptation: key challenges - scales, knowledge, and norms. Sustainability Science 5:171-184

Bjønness IM (1986) Mountain hazard perception and risk-avoiding strategies among the Sherpas of Khumbu Himal, Nepal. Mountain Research and Development 6:277-292

Björnsson, H. (1974) Explanation of jökulhlaups from Grímsvötn, Vatnajökull, Iceland. Jökull 24:1-26

Blaikie P, Cannon T, Davis I, Wisner B (1994) *At risk: natural hazards, people, vulnerability, and disasters.* Routledge, London

Bolch T, Kulkarni A, Kääb A, Huggel C, Paul F, Cogley JG, Frey H, Kargel JS, Fujita K, Scheel M, Bajracharya S, Stoffel M (2012) The state and fate of Himalayan glaciers. Science 336:310-314

Bolch T, Shea JM, Liu S, Azam FM, Gao Y, Immerzeel WW, Kulkarni A, Li H, Tahir AA, Zhang G, Zhang Y, Bannerjee A, Berthier E, Brun F, Kääb A, Kraaijenbrink P, Moholdt G, Nicholson L, Pepin N, Racoviteanu A (2019) Status and change of the cryosphere in the extended Hindu Kush Himalaya region. In: Wester P, Mishra A, Mukherji A, Shrestha AB (eds) The Hindu Kush Himalaya assessment: mountains, climate change, sustainability and people. Report of the Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP) / ICIMOD. Springer, Cham, pp 209-255

Bookhagen B, Thiede RC, Strecker MR (2005) Abnormal monsoon years and their control on erosion and sediment flux in the high, arid northwest Himalaya. Earth and Planetary Science Letters 231:131-146

Bourdieu P, trans. Nice R (1977) *Outline of a theory of practice.* Cambridge University Press, Cambridge

Brooks N (2003) Vulnerability, risk and adaptation: a conceptual framework. Working Paper 38. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich.

Brooks N, Adger WN, Kelly PM (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global Environmental Change 15:151-163.

Brooks SM, Crozier MJ, Glade T, Anderson MG (2004) Towards establishing climatic thresholds for slope instability: use of a physically-based combined soil hydrology-slope stability model. Pure and Applied Geophysics 161:881-905

Bubeck P, Otto A, Weichselgartner J (2017) Societal impacts of floods. Oxford Research Encyclopedia of Natural Hazard Science <oxfordre.com/naturalhazardscience> Accessed 1 March 2019 [doi: 10.1093/acrefore/9780199389407.013.281]

Cain DS, Barthelemy J (2008) Tangible and spiritual relief after the storm: the religious community responds to Katrina. Journal of Social Service Research 34:29-42

Caine N (1980) The rainfall intensity–duration control of shallow landslides and debris flows. Geografiska Annaler A 62:23-27

Caine N, Mool PK (1982) Landslides in the Kolpu Khola Drainage, Middle Mountains, Nepal. Mountain Research and Development 2:157-173

Calo-Blanco A, Kovářík J, Mengel F, Romero JG (2017) Natural disasters and indicators of social cohesion. PLoS ONE 12:e0176885

Cancelli A, Nova R (1985) Landslides in soil debris cover triggered by rainstorms in Valtellina (central Alps—Italy). In: Proceedings of the 4th International Conference and Field Workshop on Landslides, Tokyo. The Japan Geological Society, Tokyo, pp 267-272

Cannon SH, Gartner JE (2005) Wildfire-related debris flow from a hazards perspective. In: Jakob M, Hungr O (eds) Debris flow hazards and related phenomena. Springer, Berlin, pp 363-385

Cardona OD (2011) Disaster risk and vulnerability: notions and measurement of human and environmental insecurity. In: Brauch HG, Oswald Spring U, Mesjasz C, Grin J, Kameri-Mbote P, Chourou B, Dunay P, Birkmann J (eds) Coping with global environmental change, disasters and security – threats, challenges, vulnerabilities and risks. Hexagon Series on Human and Environmental Security and Peace, vol. 5. Springer, Berlin, pp 107-121

Cardona OD, van Aalst MK, Birkmann J, Fordham M, McGregor G, Perez R, Pulwarty RS, Schipper ELF, Sinh BT, Decamps H, Keim M, Davis I, Ebi KL, Lavell A, Mechler R, Pelling M, Pohl J, Oliver-Smith A, Thomalla F (2012) Determinants of risk: exposure and vulnerability. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation (SREX): A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge and New York, pp 65-108

Carreño ML, Cardona OD, Barbat AH (2007) Urban seismic risk evaluation: a holistic approach. Natural Hazards 40:137-172

Carrivick JL, Tweed FS (2016) A global assessment of the societal impacts of glacier outburst floods. Global Planetary Change 144:1-16

Cashman KV, Cronin SJ (2008) Welcoming a monster to the world: myths, oral tradition, and modern societal response to volcanic disasters. Journal of Volcanology and Geothermal Research 176:407-418

Centre for Bhutan Studies and GNH Research (2016) A compass towards a just and harmonious society: 2015 GNH survey report. Centre for Bhutan Studies and GNH Research, Thimpu, 334 pp

Chakraborty I, Ghosh S, Bhattacharya D, Bora A (2011) Earthquake induced landslides in the Sikkim-Darjeeling Himalayas - an aftermath of the 18th September 2011 Sikkim earthquake. Geological Survey of India, Kolkata, 8pp

Chambers R (1989) Vulnerability, coping and policy. Institute of Development Studies Bulletin 20:1-7

Chamlee-Wright E, Storr VH (2009) Club goods and post-disaster community return. Rationality and Society 21: 429-558

Chamlee-Wright E, Storr VH (2011) Social capital as collective narratives and post-disaster community recovery. The Sociological Review 59:266-282

Chang K (2010) Community cohesion after a natural disaster: insights from a Carlisle flood. Disasters 34:289-302

Chen C-W, Oguchi T, Hayakawa YS, Saito H, Chen H (2017) Relationship between landslide size and rainfall conditions in Taiwan. Landslides 14:1235-1240

Chester DK (2005) Theology and disaster studies: the need for dialogue. Journal of Volcanology and Geothermal Research 146:319-328

Cho C, Li R, Wang SY, Ho J, Robert Y (2016) Anthropogenic footprint of climate change in the June 2013 Northern India flood. Climate Dynamics 46:797-805

Clague JJ, Evans, SG (2000) A review of catastrophic drainage of moraine-dammed lakes in British Columbia. Quaternary Science Reviews 19:1763-1783

Clague JJ, O'Connor JE (2015) Glacier-related outburst floods. In: Haeberli W, Whiteman C, Shroder Jr JF (eds) Snow and ice-related hazards, risks and disasters. Academic Press, Boston, pp 487-519

Clarke GKC (2002) Hydraulics of supraglacial outburst floods. American Geophysical Union Fall Meeting, San Francisco, Abstract C61A-04

Clarke GKC (2003) Hydraulics of subglacial outburst floods: new insights from the Spring-Hutter formulation. Journal of Glaciology 49:299-313

Comberti C, Thornton TF, Korodimou M (2016) Addressing indigenous peoples' marginalisation at international climate negotiations: adaptation and resilience at the margins. Working paper, Environmental Change Institute, University of Oxford, UK

Comptroller and Auditor General of India (2015) Report of the Comptroller and Auditor General of India on performance audit of natural disaster in Uttarakhand, June 2013 (response, relief and restoration of the damaged infrastructure of immediate nature) for the year ended 31 March 2014. Government of Uttarakhand, Dehradun, 64 pp

Cooperrider DL, Whitney D, Stavros JM (2008) *Appreciative inquiry handbook for leaders of change.* 2nd edition. Crown Custom, Brunswick / Berrett-Koekler, San Francisco

Corbin J, Strauss A (2015) *Basics of qualitative research: techniques and procedures for developing grounded theory.* 4th edition. SAGE Publications, Thousand Oaks

Costa JE, Schustler RL (1988) The formation and failure of natural dams. Geological Society of America Bulletin 100:1054-1068

Coumou D, Rahmstorf S (2012) A decade of weather extremes. Nature Climate Change 2:491-496

CRED and UNISDR (2019) 2018 review of disaster events. EM-DAT (International Disaster Database) <https://emdat.be/2018-review-disaster-events> Accessed 1 March 2019

Crichton D (1999) The risk triangle. In: Ingleton J (ed) Natural disaster management. Tudor Rose, London, pp 102-103

Crook R, Manor J (1998) *Democracy and decentralisation in South Asia and West Africa.* Cambridge University Press, Cambridge

Crosby K (2008) Kamma, social collapse or geophysics? Interpretations of suffering among Sri Lankan Buddhists in the immediate aftermath of the 2004 Asian tsunami. Contemporary Buddhism 9:53-7

Crosta GB (1998) Regionalization of rainfall thresholds: an aid to landslide hazard evaluation. Environmental Geology 35:131-145

Crosta GB, Frattini P (2001) Rainfall thresholds for triggering soil slips and debris flow. In: Mugnai A, Guzzetti F, Roth G (eds) Mediterranean storms. Proceedings of the 2nd EGS Plinius Conference on Mediterranean Storms. Siena, pp 463-487

Crozier MJ (1989) Landslides: causes, consequences and environment. Routledge, London

Crozier MJ (1997) The climate-landslide couple: a southern hemisphere perspective. In: Matthews JA, Brunsden D, Frenzel B, Gläser B, Weiß MM (eds) Rapid mass movement as a source of climatic evidence for the Holocene. Gustav Fischer, Stuttgart, pp 333-354

Crozier MJ (1999) Landslides. In: Alexander DE, Fairbridge RW (eds) Encyclopedia of environmental science. Kluwer, Dordrecht, pp 371-375

Crozier MJ, Preston NJ (1999) Modelling changes in terrain resistance as a component of landform evolution in unstable hill country. In: Hergarten S, Neugebauer HJ (eds) Process modelling and landform evolution. Lecture Notes in Earth Sciences, vol. 78. Springer, Heidelberg, pp 267–284

Cruden DM, Varnes DJ (1996) Landslide types and processes. In: Turner AK, Schuster RL (eds) Landslides: investigation and mitigation. Transportation Research Board Special Report 247. National Academy Press, Washington, DC, pp 36-75

Crutzen PJ (2002) Geology of mankind: the Anthropocene. Nature 415:23

Crutzen PJ (2006) The "Anthropocene". In: Ehlers E, Krafft T (eds) Earth System Science in the Anthropocene. Springer, Berlin, Heidelberg, pp 13-18

Curtis SE, Oven KJ (2012) Geographies of health and climate change. Progress in Human Geography 36:654-666

Cutter SL, Barnes L, Berry M, Burton C, Evans E, Tate E, Webb J (2008) A place-based model for understanding community resilience to natural disasters. Global Environmental Change 18:598-606

Dahal RK, Hasegawa S (2008) Representative rainfall thresholds for landslides in the Nepal Himalaya. Geomorphology 100:429-443

Dahal RK, Hasegawa S, Yamanaka M, Nishino K (2006) Rainfall triggered flow-like landslides: understanding from southern hills of Kathmandu, Nepal and Northern Shikoku, Japan. In: Proceedings of the 10th International Congress of the IAEG, The Geological Society of London, Paper No. 819

Dake K (1992) Myths of nature: culture and the social construction of risk. Journal of Social Issues 48:21-37

Das S, Kar NS, Bandyopadhyay S (2015) Glacial lake outburst flood at Kedarnath, Indian Himalaya: a study using digital elevation models and satellite images. Natural Hazards 77:769-786

Dash SK, Nair A, Kulkarni M, Mohanty UC (2011) Characteristic changes in the long and short spells of different rain intensities in India. Theoretical and Applied Climatology 105:563-570

Delrieu G, Nicol J, Yates E, Kirstetter P-E, Creutin J-D, Anquetin S, Obled C, Saulnier G-M, Ducrocq V, Gaume E, Payrastre O, Andrieu H, Ayral P-A, Bouvier C, Neppel L, Livet M, Lang M, du-Châtelet JP, Walpersdorf A, Wobrock W (2005) The catastrophic flash-flood event of 8-9 September 2002 in the Gard region, France: a first case study for the Cévennes-Vivarais Mediterranean Hydrometeorological Observatory. Journal of Hydrometeorology 6:34-52

Denevan WM (1983) Adaptation, variation, and cultural geography. The Professional Geographer 35:399-407

Denzin NK (1989) *The research act: a theoretical introduction to sociological methods.* 3rd edition. Prentice Hall, Englewood Cliffs

Dexter LA (2006) *Elite and specialised interviewing (with a new introduction by Alan Ware and Martín Sánchez-Jankowski).* ECPR Press, Colchester

DFID (2000) Sustainable livelihood guidance sheets. Department for International Development, London

Dikau R, Brunsden D, Schrott L, Ibsen M (eds) (1996) *Landslide recognition: identification, movement and causes.* Wiley, Chichester

Dikshit A, Satyam DN (2018) Estimation of rainfall thresholds for landslide occurrence in Kalimpong, India. Innovative Infrastructure Solutions 3:24 [e-publication ahead of print, doi: 10.1007/s41062-018-0132-9]

Dimri AP, Niyogi D, Barros AP, Ridley J, Mohanty UC, Yasunari, T, Sikka DR (2015) Western disturbances: a review. Reviews of Geophysics 53:225-246

Disaster Mitigation and Management Centre (2015) State Disaster Management Action Plan for the State of Uttarakhand. Uttarakhand Secretariat, Dehradun, 175 pp

DMMC (2012) Sikkim earthquake of 18th September 2011. Disaster Mitigation and Management Centre, Department of Disaster Management, Uttarakhand Secretariat, Dehradun, 28 pp

Dobhal DP, Gupta AK, Mehta M, Khandelwal DD (2013) Kedarnath disaster: facts and plausible causes. Current Science 105:171-174

Dueck A, Byron K (2018) Community, spiritual traditions, and disasters in collective societies. Journal of Psychology and Theology 39:244-254

Durga Rao KHV, Venkateshwar Rao V, Dadhwal VK, Diwakar PG (2014) Kedarnath flash floods: a hydrological and hydraulic simulation study. Current Science 106:598-603

ETCCDI (2009) Definitions of the 27 core indices. ETCCDI/CRD climate change indices webpage <etccdi.pacificclimate.org/list_27_indices.shtml> Accessed 4 December 2018

Engle NL (2011) Adaptive capacity and its assessment. Global Environmental Change 21:647-656

Evans SG, Clague JJ (1993) Glacier-related hazards and climate change. In: Bras R (ed) The world at risk: natural hazards and climate change. AIP conference proceedings, vol. 277. American Institute of Physics, New York, pp 48–60

Evans SG, Clague JJ (1994) Recent climate change and catastrophic geomorphic processes in mountain environments. Geomorphology 10:107–128

Folke C (2006) Resilience: the emergence of a perspective for social-ecological systems analyses. Global Environmental Change 16:253-267

Ford JD, Cameron L, Rubis J, Maillet M, Nakashima D, Willox AC, Pearce T (2016) Including indigenous knowledge and experience in IPCC assessment reports. Nature Climate Change 6:349-353

Ford JD, Keskitalo ECH, Smith T, Pearce T, Berrang-Ford L, Duerden F, Smit B (2010) Case study and analogue methodologies in climate change vulnerability research. WIREs Climate Change 1:374-392

Forsyth T, Evans N (2013) What is autonomous adaptation? Resource scarcity and smallholder agency in Thailand. World Development 43:56-66

Fox NJ (1999) Postmodern reflections on 'risk', 'hazards' and life choices. In Lupton D (ed) Risk and sociocultural theory. Cambridge University Press, Cambridge, pp 12-33

Froehlich W, Gil E, Kasza I, Starkel L (1990) Thresholds in the transformation of slopes and river channels in the Darjeeling Himalaya, India. Mountain Research and Development 10:301-312

Froude MJ, Petley DN (2018) Global fatal landslide occurrence from 2004 to 2016. Natural Hazards and Earth System Sciences 18:2161-2181

Gabet EJ, Burbank DW, Putkonen JK, Pratt-Sitaula BA, Oiha T (2004) Rainfall thresholds for landsliding in the Himalayas of Nepal. Geomorphology 63:131-143

Gaillard J-C, Texier P (2010) Religions, natural hazards, and disasters: an introduction. Religion 40:81-84

Gallopín GC (2006) Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change 16:293-303

GAPHAZ (2017) Assessment of glacier and permafrost hazards in mountain regions. Technical guidance document. Standing Group on Glacier and Permafrost Hazards in Mountains (GAPHAZ) of the International Association of Cryospheric Sciences (IACS) and the International Permafrost Association (IPA), Zurich and Lima, 72 pp

Garrison MB, Sasser DD (2009) Families and disasters: making meaning out of adversity. In: Cherry KE (ed) Lifespan perspectives on natural disasters. Springer, New York, pp 113-130

Gautam R, Hsu NC, Lau K-M (2010) Premonsoon aerosol characterization and radiative effects over the Indo-Gangetic Plains: implications for regional climate warming. Journal of Geophysical Research 115:D17208

Giddens A (1984) The constitution of society: outline of the theory of structuration. University of California Press, Berkeley and Los Angeles

Gilbert RO (1987) *Statistical methods for environmental pollution monitoring.* Van Nostrand Reinhold, New York

Glade T (1998) Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand. Environmental Geology 35:160-174

Glade T (2004) Vulnerability assessment in landslide risk analysis. Die Erde 134:121-138

Glade T (2000) Modelling landslide-triggering rainfalls in different regions in New Zealand – the soil water status model. Zeitschrift für Geomorphologie 122:63-84

Glade T, Crozier MJ (2005) The nature of landslide hazard impact. In: Glade T, Anderson MG, Crozier MJ (eds) Landslide Hazard and Risk. Wiley, Chichester, pp 43-74

Glade T, Kappes MS, Frigerio S, Malet J-P (2012) Multi-hazard exposure analyses with MultiRISK – a platform for user-friendly analysis. INTERPRAEVENT 12th Congress Conference Proceedings, pp 487-495

Goswami BN, Venugopal V, Sengupta D, Madhusoodanan MS, Xavier PK (2006) Increasing trend of extreme rain events over India in a warming environment. Science 314:1442-1445

Government of Sikkim (2011) Sikkim action plan on climate change (2012-2030): draft report. Government of Sikkim, Gangtok, 160 pp

Government of Uttarakhand (2014) Uttarakhand action plan on climate change: Transforming crisis into opportunity. Uttarakhand Secretariat, Dehradun, 226 pp

Govindha Raj BK, Kumar VK, and Remya SN (2012) Remote sensing-based inventory of glacial lakes in Sikkim Himalaya: semi-automated approach using satellite data. Geomatics, Natural Hazards and Risk 4:241-253

Guzzetti F, Peruccacci S, Rossi M, Stark CP (2008) The rainfall intensity-duration control of shallow landslides and debris flows: an update. Landslides 5:3-17

Haeberli W (1983) Frequency and characteristics of glacier floods in the Swiss Alps. Annals of Glaciology 4:85-90

Haeberli W, Whiteman C (2015) Snow and ice-related hazards, risks, and disasters: a general framework. In: Shroder JF, Haeberli W, Whiteman C (eds) Snow and ice-related hazards, risks and disasters. Academic Press, Amsterdam, Waltham and Oxford, pp 1-34

Hearn GJ, Shakya NM (2017) Engineering challenges for sustainable road access in the Himalayas. Quarterly Journal of Engineering Geology and Hydrogeology 50:69-80

Haerter JO, Berg P (2009) Unexpected rise in extreme precipitation caused by a shift in rain type? Nature Geoscience 2:372-373

Handmer J (2003) We are all vulnerable. Australian Journal of Emergency Management 18:55-60

Hardwick-Jones R, Westra S, Sharma A (2010) Observed relationships between extreme sub-daily precipitation, surface temperature and relative humidity. Geophysical Research Letters 37: L22805

Hasson S, Lucarini V, Khan MR, Petitta M, Bolch T, Gioli G (2014) Early 21st century snow cover state over the western river basins of the Indus River system. Hydrology Earth System Sciences 18:4077-4100

Heyd T, Brooks N (2009) Exploring cultural dimensions of adaptation to climate change. In: Adger WN, Lorenzoni I, O'Brien K (eds) Adapting to climate change: thresholds, values, governance. Cambridge University Press, Cambridge, pp 269-282

Hollander M, Wolfe DA (1973) *Nonparametric statistical methods.* Wiley, New York

Holling CS (1973) Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4:1-23

Hong CC, Hsu HH, Lin NH, Chiu H (2011) Roles of European blocking and tropical-extratropical interaction in the 2010 Pakistan flooding. Geophysical Research Letters 38:L13806

Huggel C (2009) Recent extreme slope failures in glacial environments: effects of thermal perturbation. Quaternary Science Reviews 28:1119-1130

Hungr O, Evans SG, Bovis MJ, Hutchinson JN (2001) A review of the classification of landslides of the flow type. Environmental and Engineering Geoscience 7:221-238

Hutchinson J (1988) General report: morphological and geotechnical parameters of landslides in relation to geology and hydrogeology. In: Bonnard C (ed) Proceedings of the 5th International Symposium on Landslides, Lausanne. AA Balkema, Rotterdam, pp 3-35

Ice Stupa Team (2016) Ladakh shares its experience with Sikkim in averting a Kedarnath/Phugtal type disaster. Blog <icestupa.org/news/slug-rb4s71/> Accessed 1 November 2017

ICIMOD (2003, 2004, 2005) Reports of the Asia-Pacific Network for Global Change Research 2004-03-CMY project 'Inventory of glaciers and glacial lakes and the identification of potential glacial lake outburst floods (GLOFs) affected by global warming in the mountains of India, Pakistan and China/Tibet Autonomous Region'. DVD from International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal, produced in 2007

IFAD (2009) Good practices in participatory mapping. International Fund for Agricultural Development, Rome, 55 pp

Ingty T (2017) High mountain communities and climate change: adaptation, traditional ecological knowledge, and institutions. Climatic Change 145:41-55

Innes JL (1983) Debris flows. Progress in Physical Geography 7:469-501

IPCC (2000) An overview of scenarios. In: Nakićenović N et al. Special Report on Emissions Scenarios. Cambridge University Press, Cambridge, pp 167-238

IPCC (2001) Glossary of terms. In: McCarthy JJ, Canziani OF, Leary NA, Dokken DJ, White KS (eds) Climate change 2001: Impacts, adaptation, and vulnerability. Contribution of Working Group II to the Third

Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 981-996

IPCC (2007a) Glossary. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, and Hanson CE (eds) Climate Change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 869-883

IPCC (2012a) Glossary of terms. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation (SREX): A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge and New York, pp 555-564

IPCC (2012b) Summary for policymakers. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation (SREX): A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge and New York, pp 1-19

IPCC (2013) Summary for policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp 3-29

IPCC (2014) Glossary. In: Agard J, Schipper ELF, Birkmann J, Campos M, Dubeux C, Nojiri Y, Olsson L, Osman-Elasha B, Pelling M, Prather MJ, Rivera-Ferre MG, Ruppel OC, Sallenger A, Smith KR, St Clair AL, Mach KJ, Mastrandrea MD, Bilir TE (eds) Climate change 2014: Impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp 1757-1776

Ives JD, Shrestha RB, Mool PK (2010) Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment. ICIMOD, Kathmandu, 56 pp

Janoff-Bulman R, McPherson Frantz C (1997) The impact of trauma on meaning: from meaningless world to meaningful life. In: Power MJ, Brewin CR (eds) The transformation of meaning in psychological therapies: integrating theory and practice*.* Wiley, Hoboken, pp 91-106

Joakim EP, Mortsch L, Oulahen G (2015) Using vulnerability and resilience concepts to advance climate change adaptation. Environmental Hazards 14:137-155

Joakim EP, White RS (2015) Exploring the impact of religious beliefs, leadership, and networks on response and recovery of disaster-affected populations: a case study from Indonesia. Journal of Contemporary Religion 30:193-212

Jogesh A, Dubash NK (2014) Mainstreaming climate change in state development planning: An analysis of the Sikkim Action Plan on Climate Change. Centre for Policy Research (CPR) Climate Initiative, working paper, New Delhi

Johnston I (2015) Traditional warning signs of cyclones on remote islands in Fiji and Tonga. Environmental Hazards 14:210-223

Jones RN, Boer R (2004) Assessing current climate risks. In: Lim B, Spanger-Siegfried E, Burton I, Malone EL, Huq S (eds) Adaptation policy frameworks for climate change: developing strategies, policies and measures. Cambridge University Press, Cambridge and New York, pp 91-118

Joseph S, Sahai AK, Sharmila S, Abhilash S, Borah N, Chattopadhyay R, Pillai PA, Rajeevan M, Kumar A (2015) North Indian heavy rainfall event during June 2013: diagnostics and extended range prediction. Climate Dynamics 44:2049-2065

JRDNA Team (2013) India - Uttarakhand disaster, June 2013: Joint rapid damage and needs assessment report. Government of Uttarakhand, World Bank and Asian Development Bank, Dehradun, 87 pp

Jung CG, trans. Dell WS, Baynes CF (1955) *Modern man in search of a soul.* Harcourt, New York

Jung CG, trans. Hull RFC (1969) *The archetypes and the collective unconscious*, *C.G. Jung: the collected works, vol. 9 (Part 1)*. Princeton University Press, Princeton

Kanungo DP, Sharma S (2014) Rainfall thresholds for prediction of shallow landslides around Chamoli-Joshimath region, Garhwal Himalayas, India. Landslides 11:629-638

Karl TR, Nicholls N, Ghazi A (1999) CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes: Workshop summary. Climatic Change 42:3-7

Karnik SJ, Suri KB (1995) The law of karma and social work considerations. International Social Work 38:365-377

Kaul, V (2012) Enhancing community adaptation and resilience to climate change-related glacial hazards and extreme hydrometeorological events in the Upper Chenab Basin, Western Himalaya. Masters dissertation. Environmental Change Institute, University of Oxford, Oxford

Kaul V, Thornton TF (2014) Resilience and adaptation to extremes in a changing Himalayan environment. Regional Environmental Change 14:683-698

Kelman I (2017) Linking disaster risk reduction, climate change, and the sustainable development goals. Disaster Prevention and Management: An International Journal 26:254-258

Kelman I, Gaillard JC, Lewis J, Mercer J (2016) Learning from the history of disaster vulnerability and resilience research and practice for climate change. Natural Hazards 82:S129-S143

Kelman I, Gaillard JC, Mercer J (2015) Climate change's role in disaster risk reduction's future: beyond vulnerability and resilience. International Journal of Disaster Risk Science 6:21-27

Kendall MG (1975) *Rank correlation methods.* 4th edition. Charles Griffin, London

Khanal NR, Watanabe T (2005) Landslide and debris flow hazards induced by heavy precipitation in Nepal. Proceedings of the International Symposium on Landslide Hazard in Orogenic Zone from the Himalaya to Island Arc in Asia, Kathmandu, pp 111-118

Kharin VV, Zwiers FW, Zhang X, Hegerl GC (2007) Changes in temperature and precipitation extremes in the IPCC ensemble global coupled model simulations. Journal of Climate 20:1419-1444

Klein RJT, Nicholls RJ, Thomalla F (2003) Resilience to natural hazards: How useful is this concept? Global Environmental Change Part B: Environmental Hazards 5:35-45

Koffka K (1935) *Principles of gestalt psychology*. Lund Humphries, London

Kollmair M, Gamper St. (2002) The sustainable livelihood approach. Input paper for the Integrated Training Course of NCCR North-South, 9-20 September 2002. Development Study Group, University of Zurich, Switzerland

Komori J (2008) Recent expansions of glacial lakes in the Bhutan Himalayas. Quaternary International 184:177-186

Kothawale DR, Revadekar JV, Rupa Kumar K (2010) Recent trends in pre-monsoon daily temperature extremes over India. Journal of Earth System Science 119:51-65

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift 15:259-263

Krishna Kumar K, Kamala K, Rajagopalan B, Hoerling MP, Eischeid JK, Patwardhan SK, Srinivasan G, Goswami BN, Nemani R (2011a) The once and future pulse of Indian monsoonal climate. Climate Dynamics 36:2159-2170

Krishna Kumar K, Patwardhan SK, Kulkarni A, Kamala K, Koteswara Rao K, Jones R (2011b) Simulation and future projections of summer monsoon climate over India by a high-resolution regional climate model (PRECIS). Current Science 101:312-326

Krishna Kumar K, Rajagopalan B, Hoerling M, Bates G, Cane M (2006) Unraveling the mystery of Indian monsoon failure during El Niño. Science 314:115-119

Krishnan R, Shrestha AB, Ren G, Rajbhandari R, Saeed S, Sanjay J, Syed MA, Vellore R, Xu Y, You Q, Ren Y, Dimri AP, Lutz A, Singh P, Sun X, Zhan Y (2019) Unravelling climate change in the Hindu Kush Himalaya: rapid warming in the mountains and increasing extremes. In: Wester P, Mishra A, Mukherji A, Shrestha AB (eds) The Hindu Kush Himalaya assessment: mountains, climate change, sustainability and people. Report of the Hindu Kush Himalayan Monitoring and Assessment Programme (HIMAP) / ICIMOD. Springer, Cham, pp 57-97

Krueger RA, Casey MA (2008) *Focus groups: a practical guide for applied research.* 4th edition. SAGE Publications, London

Kulkarni A, Patwardhan S, Krishna Kumar K, Ashok K, Krishnan R (2013) Projected climate change in the Hindu Kush-Himalayan region by using the high-resolution regional climate model PRECIS. Mountain Research and Development 33:142–151

Kumar NT, Mohan M, Shukla SP (2013) A report on the updation of glacier inventory of Sikkim Himalaya. Geological Survey of India, Gangtok, 49 pp

Kvale S (1996) *InterViews: an introduction to qualitative research interviewing.* SAGE Publications, London

Lane SN, Odoni N, Landström C, Whatmore SJ, Ward N, Bradley S (2010) Doing flood risk science differently: an experiment in radical scientific method. Transactions of the Institute of British Geographers 36:15-36

Larsen MC, Simon A (1993) A rainfall intensity-duration threshold for landslides in a humid-tropical environment, Puerto Rico. Geografiska Annaler A 75:13-23

Larson AM (2005) Democratic decentralization in the forestry sector: lessons learned from Africa, Asia and Latin America. In: Colfer CJP, Capistrano D (eds) The politics of decentralization: forests, power and people. Earthscan, London, pp 32-62

Lau WK, Kim K-M (2012) The 2010 Pakistan flood and the Russia heat wave: teleconnection of extremes. Journal of Hydrometeorology 13:392-403

Lavigne F, De Coster B, Juvin N, Flohic F, Gaillard J-C, Texier P, Morin J, Sartohadi J (2008) People's behaviour in the face of volcanic hazards: perspectives from Javanese communities, Indonesia. Journal of Volcanology and Geothermal Research 172:273–287

Lenderink G, Mok HY, Lee TC, van Oldenborgh GJ (2011) Scaling and trends of hourly precipitation extremes in two different climate zones - Hong Kong and the Netherlands, Hydrology and earth System Sciences 8:4701-4719

Lenderink G, van Meijgaard E (2008) Increase in hourly precipitation extremes beyond expectations from temperature changes. Nature Geoscience 1:511-514

Lenderink G, van Meijgaard E (2010) Linking increases in hourly precipitation extremes to atmospheric temperature and moisture changes. Environmental Research Letters 5:025208

Lenton TM, Held H, Kriegler E, Hall JW, Lucht W, Rahmstorf S, Schellnhuber HJ (2008) Tipping elements in the Earth's climate system. Proceedings of the National Academy of Sciences 105:1786-1793

Linley PA, Joseph S (2005) Positive change following trauma and adversity: a review. Journal of Traumatic Stress 17: 11-21

Liu X, Cheng Z, Yan L, Yin Z-Y (2009) Elevation dependency of recent and future minimum surface air temperature trends in the Tibetan Plateau and its surroundings. Global and Planetary Change 68:164-174

Loppie C (2007) Learning from the grandmothers: incorporating indigenous principles into qualitative research. Qualitative Health Research 17:276-284

Loriaux JM, Lenderink G, De Roode SR, Siebesma AP (2013), Understanding convective extreme precipitation scaling using observations and an entraining plume model. Journal of the Atmospheric Sciences 70:3641-3655

Lövbrand E, Beck S, Chilvers J, Forsyth T, Hedrén J, Hulme M, Lidskog R, Vasileiadou E (2015) Who speaks for the future of Earth? How critical social science can extend the conversation on the Anthropocene. Global Environmental Change 32:211-218

Lowe P, Phillipson J (2009) Barriers to research collaboration across disciplines: scientific paradigms and institutional practices. Environment and Planning A 41:1171-1184

Loza CAA, Asis MS, Albis EC, Bulao JB, Conde JCM (2016) Metonymies of Tawonglipod in Cagliliog, Tinambac, Camarines Sur: counter-memory to Christian hegemony in Bilkol, Philippines. Advanced Science Letters 22:1589-1592

Ludin SM, Rohaizat M, Arbon P (2018) The association between social cohesion and community disaster resilience: A cross-sectional study. Health and Social Care in the Community [e-publication ahead of print, doi: 10.1111/hsc.12674]

Madhura RK, Krishnan R, Revadekar JV, Mujumdar M, Goswami BN (2015) Changes in western disturbances over the Western Himalayas in a warming environment. Climate Dynamics 44:1157-1168

Mann HB (1945) Non-parametric tests against trend. Econometrica 13:245-259

Martha TR, Roy P, Babu Govindharaj K, Vinod Kumar K, Diwakar PG, Dadhwal VK (2015) Landslides triggered by the June 2013 extreme rainfall event in parts of Uttarakhand state, India. Landslides 12:135-146

Martin DH (2012) Two-eyed seeing: a framework for understanding indigenous and non-indigenous approaches to indigenous health research. Canadian Journal of Nursing Research 44:20-42

Masica CP (1991) *The Indo-Aryan languages.* Cambridge University Press, Cambridge

Mason J (2002a) Qualitative interviewing: asking, listening and interpreting. In: May T (ed) *Qualitative research in action.* SAGE Publications, London, pp 225-241

Mason J (2002b) *Qualitative researching.* 2nd edition. SAGE Publications, London

Maurer JM, Schaefer JM, Rupper S, Corley A (2019) Acceleration of ice loss across the Himalayas over the past 40 years. Science Advances 5:eaav7266

Mazzocchi F (2006) Western science and traditional knowledge: despite their variations, different forms of knowledge can learn from each other. EMBO Reports 7:463-466

Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, Kitoh A, Knutti R, Murphy JM, Noda A, Raper SCB, Watterson IG, Weaver AJ, Zhao Z-C (2007) Global climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate Change 2007: the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp 747-845

Mehta M, Dobhal DP, Kesarwani K, Pratap B, Kumar A, Verma A (2014) Monitoring of glacier changes and response time in Chorabari Glacier, Central Himalaya, Garhwal, India. Current Science 107:281-289

Mehta M, Shukla T, Bhambri R, Gupta AK, Dobhal DP (2017) Terrain changes, caused by the 15-17 June 2013 heavy rainfall in the Garhwal Himalaya, India: a case study of Alaknanda and Mandakini basins. Geomorphology 284:53-71

Mercer J (2010) Disaster risk reduction or climate change adaptation: are we reinventing the wheel? Journal of International Development 22: 247-264

Merli C (2012) Religion and disaster in anthropological research. In: Kearnes MB, Klauser F, Lane S (eds) Critical risk research: practices, politics and ethics. Wiley (e-book), pp 43-58

Miller F, Osbahr H, Boyd E, Thomalla F, Bharwani S, Ziervogel G, Walker B, Birkmann J, van der Leeuw S, Rockström J, Hinkel J, Downing T, Folke C, Nelson D (2010) Resilience and vulnerability: complementary or conflicting concepts? Ecology and Society 15:11

Min S-K, Zhang X, Zwiers FW, Hegerl GC (2011) Human contribution to more-intense precipitation extremes. Nature 470:378-381

Mitchell JT (2000) The hazards of one's faith: hazard perceptions of South Carolina Christian clergy. Global Environmental Change Part B: Environmental Hazards 2:25-41

Molnar P, Fatichi S, Gaál L, Szolgay J, Burlando P (2015) Storm type effects on super Clausius-Clapeyron scaling of intense rainstorm properties with air temperature. Hydrology and Earth System Sciences 19:1753-1766

Morgan DL (1997) *Focus groups as qualitative research.* 2nd edition. SAGE Publications, Thousand Oaks

Morgan DL, Spanish MT (1984) Focus groups: a new tool for qualitative research. Qualitative Sociology 7:253-270

Moseley C, Berg P, Haerter JO (2013) Probing the precipitation life cycle by iterative rain cell tracking. Journal of Geophysical Research: Atmospheres 118:13361-13370

Moser M, Hohensinn F (1983) Geotechnical aspects of soil slips in Alpine regions. Engineering Geology 19:185-211

Murphy BL (2007) Locating social capital in resilient community-level emergency management. Natural Hazards 41: 297–315

Nakagawa Y, Shaw R (2004) Social capital: a missing link to disaster recovery. International Journal of Mass Emergencies and Disasters 22:5-34

Nicolini D (2012) *Practice theory, work, and organization: an introduction.* Oxford University Press, Oxford

NDMA (2009) National policy on disaster management. Ministry of Home Affairs, Government of India, 42 pp < nidm.gov.in/PDF/policies/ndm_policy2009.pdf> Accessed 14 June 2018

NDMA (2018) National disaster management plan. National Disaster Management Authority, Ministry of Home Affairs, Government of India, New Delhi, 298 pp

Nelson DR, Adger WN, Brown K (2007) Adaptation to environmental change: contributions of a resilience framework. Annual Review of Environment and Resources 32:395-419

Nepal Climate Vulnerability Study Team (2009) Vulnerability through the eyes of the vulnerable: climate change induced uncertainties and Nepal's development predicaments. Institute for Social and Environmental Transition, Nepal (ISET-N), Kathmandu and Institute for Social and Environmental Transition (ISET), Boulder, Colorado, 95 pp

NITI Aayog (2017) Report of the NITI Aayog working group on inventory and revival of springs in Himalayas for water security. Department of Science and Technology, Government of India, 102 pp

Nunn PD (2014) Geohazards and myths: ancient memories of rapid coastal change in the Asia-Pacific region and their value to future adaptation. Geoscience Letters 1:3

O'Brien MJ, Holland TD (1992) The Role of adaptation in archaeological explanation. American Antiquity 57:36-59

Oliver-Smith A, Hoffman SM (2002) Introduction: Why anthropologists should study disasters. In: Hoffman SM, Oliver-Smith A (eds) Catastrophe and culture: the anthropology of disaster. School of American Research Press, Santa Fe, pp 3-22

Omprakash S (1989) The doctrine of karma: its psychosocial consequences. American Journal of Community Psychology 17:133-145

Orlove B, Milch K, Zaval L, Ungemach C, Brugger J, Dunbar K, Jurt C (2019) Framing climate change in frontline communities: anthropological insights on how mountain dwellers in the USA, Peru, and Italy adapt to glacier retreat. Regional Environmental Change 19:1295-1309

Ortner SB (1984) Theory in anthropology since the sixties. Comparative Studies in Society and History 26: 126-166

Oven KJ (2009) Landscape, livelihoods and risk: community vulnerability to landslides in Nepal. Doctoral dissertation. Durham University, Durham. Available at Durham E-Theses Online: <http://etheses.dur.ac.uk/183/>

Oven KJ, Petley DN, Rigg JR, Dunn CE, Rosser NJ (2008) Landscape, livelihoods and risk: a study of community vulnerability to landslide events in Central Nepal. In: Aryal KR, Gadema Z (eds) Climate change and disaster risk reduction. Disaster and Development Centre, Northumbria University, Newcastle upon Tyne, pp 94-102

Paeth H, Scholten A, Friedrichs P, Hense A (2008) Uncertainties in climate change prediction: El Niño-Southern Oscillation and monsoons. Global and Planetary Change 60:265-288

Pall P, Allen M, Stone D (2007) Testing the Clausius-Clapeyron constraint on changes in extreme precipitation under CO_2 warming. Climate Dynamics 28:351-363

Pant GB, Rupa Kumar K (eds.) (1997) *Climates of South Asia.* Wiley, Chichester

Panthou G, Mailhot A, Laurence E, Talbot G (2014) Relationship between surface temperature and extreme rainfalls: a multi-time-scale and event-based analysis. Journal of Hydrometeorology 15:1999-2011

Parliament of India (2005) Disaster Management Act, 2005. The Gazette of India 64:1-29 <ndma.gov.in/images/ndma-pdf/DM_act2005.pdf> Accessed 1 December 2018

Pelling M (1997) What determines vulnerability to floods: a case study in Georgetown, Guyana. Environment and Urbanization 9:203-226

Pelling M (2011) *Adaptation to climate change: from resilience to transformation.* Routledge, Abingdon

Pelling M, High C (2005) Understanding adaptation: What can social capital offer assessments of adaptive capacity? Global Environmental Change 15: 308-319

Peruccacci S, Brunetti MT, Gariano SL, Melillo M, Rossi M, Guzzetti F (2017) Rainfall thresholds for possible landslide occurrence in Italy. Geomorphology 290:39-57

Peterson TC, Folland C, Gruza G, Hogg W, Abdallah M, Plummer N (2001) Report on the activities of the working group on climate change detection and related rapporteurs 1998-2001. World Meteorological Organization, Geneva, Switzerland, 143 pp

Petley DN, Hearn GJ, Hart A, Rosser NJ, Dunning SA, Oven K, Mitchell WA (2007) Trends in landslide occurrence in Nepal. Natural Hazards 43:23-44

Petley DN, Rosser NJ, Karim D, Wali S, Ali N, Nasab N, Shaban K (2010) Non-seismic landslide hazards along the Himalayan Arc. In: Williams AL, Pinches GM, Chin CY, McMorran TJ, Massey CI (eds) Geologically Active. CRC Press, London, pp 143-154

Petley D (2012) Global patterns of loss of life from landslides. Geology 40:927-930

Petley D (2013) Reconstructing the events at Kedarnath using data, images and eyewitness reports. The Landslide Blog, American Geophysical Union, 4 July 2013: blogs.agu.org/landslideblog

Piciullo L, Calvello M, Cepeda J (2018) Territorial early warning systems for rainfall-induced landslides. Earth-Science Reviews 179:228-247

Pinto N (2018) BJP MLA believes Kerala being punished for eating beef. India Today (online), Bengaluru, 26 August

Polsky C, Neff R, Yarnal B (2007) Building comparable global change vulnerability assessments: The vulnerability scoping diagram. Global Environmental Change 17:472-485

Postill J (2010) Introduction: Theorising media and practice. In: Bräuchler B, Postill J (eds) Theorising media and practice. Berghahn, Oxford and New York, pp 1-32

Prime Minister's Council on Climate Change (2008) National Action Plan on Climate Change. Government of India, New Delhi, 49 pp

PTI (2013) After 17 days, rescue work in Uttarakhand over, 1.1 lakh people evacuated. The Times of India (Online), Dehradun, 2 July

Raina VK (2009) Himalayan glaciers: a state-of-art review of glacial studies, glacial retreat and climate change. Discussion paper, Ministry of Environment and Forests, Government of India, 56 pp

Ramachandran R (2013) Why Kedarnath happened. Frontline (Online), Chennai, 26 July

Rao CAR, Raju BMK, Rao AVMS, Rao KV, Rao VUM, Ramachandran K, Nagasri K, Dupdal R, Samuel J, Shankar KR, Rao MS, Maheswari M (2018) Climate change in Uttarakhand: projections, vulnerability and farmers' perceptions. Journal of Agrometeorology 20:37-41

Rathore LS, Attri SD, Jaswal AK (2013) State level climate change trends in India. Meterological Monograph No. ESSO/IMD/EMRC/02/2013, India Meteorological Department, 147 pp

Reckwitz A (2002) Toward a theory of social practices: a development in culturalist theorizing. European Journal of Social Theory 5:243-263

Reichenbach P, Cardinali M, De Vita P, Guzzetti F (1998) Regional hydrological thresholds for landslides and floods in the Tiber River Basin (Central Italy). Environmental Geology 35:146-159

Ren Y-Y, Ren G-Y, Sun X-B, Shrestha AB, You Q-L, Zhan Y-J, Rajbhandari R, Zhang P-F, Wen K-M (2017) Observed changes in surface air temperature and precipitation in the Hindu Kush Himalayan region over the last 100-plus years. Advances in Climate Change Research 8:148-156

Reynolds JM (1992) The identification and mitigation of glacier-related hazards: examples from the Cordillera Blanca, Peru. In: McCall GJH, Laming DJC, Scott SC (eds) Geohazards. Chapman and Hall, London, pp 143-157

Reynolds JM (1998) High-altitude glacial lake hazard assessment and mitigation: a Himalayan perspective. Engineering Geology Special Publications 15:25-34

Reynolds JM, Richardson SD (1999) Glacial hazards. In: Ingleton J (ed) Natural disaster management. UN Secretariat for the IDNDR, Tudor Rose, Leicester, pp 64-65

Ribot JC (2002) Democratic decentralization of natural resources: institutionalizing popular participation. World Resources Institute, Washington, DC, 30 pp

Richardson SD, Reynolds JM (2000) An overview of glacial hazards in the Himalayas. Quaternary International 65:31-47

Rivera JD, Nickels AE (2014) Social capital, community resilience, and faith-based organisations in disaster recovery: a case study of Mary Queen of Vietnam Catholic Church. Risk, Hazards & Crisis in Public Policy 5:178-211

Robbins P (2012) *Political ecology: a critical introduction.* 2nd edition. Wiley-Blackwell, New York

Roberts MJ (2005) Jökulhlaups: a reassessment of floodwater flow through glaciers. Reviews of Geophysics 43:RG1002

Rupa Kumar K, Sahai AK, Krishna Kumar K, Patwardhan SK, Mishra PK, Revadekar JV, Kamala K, Pant GB (2006) High-resolution climate change scenarios for India. Current Science 90:334-345

Rural Development and Migration Commission (2018) Interim report on the status of migration in Gram Panchayats of Uttarakhand. Government of Uttarakhand, Dehradun, 86 pp

Rusli N, Majid MR, Din AHM (2014) Google Earth's derived digital elevation model: a comparative assessment with Aster and SRTM data. IOP Conference Series: Earth and Environmental Science 18:012065

Salmi T, Määttä A, Anttila P, Ruoho-Airola T, Amnell T (2002) Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates – the Excel template application MAKESENS. Publications on Air Quality No. 31, Finnish Meteorological Institute, Helsinki, 35 pp

Sanjay J, Krishnan R, Shrestha AB, Rajbhandari R, Ren G-Y (2017) Downscaled climate change projections for the Hindu Kush Himalayan region using CORDEX South Asia regional climate models. Advances in Climate Change Research 8: 185-198

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association 63:1379-1389

Sarewitz D, Pielke R, Keykhah M (2003) Vulnerability and risk: some thoughts from a political and policy perspective. Risk Analysis 23:805-810

Schatzki T, Knorr Cetina K, von Savigny E (eds) (2001) The practice turn in contemporary theory. Routledge, London

Schipper L (2010) Religion as an integral part of determining and reducing climate change and disaster risk: an agenda for research. In: Voss M (ed) Climate change: the social science perspective. VS Verlag, Wiesbaden, pp 377-393

Schipper L, Merli C, Nunn P (2014) How religion and beliefs influence perceptions of and attitudes towards risk. In: Cannon T, Schipper L, Bankoff G, Krüger F (eds) World disasters report 2014: focus on culture and risk. International Federation of Red Cross and Red Crescent Societies, Geneva, pp 37-63

Schipper ELF, Thomalla F, Vulturius G, Davis M, Johnson K (2016) Linking disaster risk reduction, climate change and development. International Journal of Disaster Resilience in the Built Environment 7:216-228

Schlehe J (2010) Anthropology of religion: disasters and the representations of tradition and modernity. Religion 40:112-120

Schumm SA (1979) Geomorphic thresholds: the concept and its applications. Transactions of the Institute of British Geographers (New Series) 4:485-515

Segoni S, Piciullo L, Gariano SL (2018) A review of the recent literature on rainfall thresholds for landslide occurrence. Landslides 15:1483-1501

Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, Luo Y, Marengo J, McInnes K, Rahimi M, Reichstein M, Sorteberg A, Vera C, Zhang X (2012): Changes in climate extremes and their impacts on the natural physical environment. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation (SREX): A special report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge and New York, pp 109-230

Sengupta A, Gupta S, Anbarasu K (2010) Rainfall thresholds for the initiation of landslide at Lanta Khola in north Sikkim, India. Natural Hazards 52:31-42

Sharma RK, Pradhan P, Sharma NP, Shrestha DG (2018) Remote sensing and in situ-based assessment of rapidly growing South Lhonak glacial lake in eastern Himalaya, India. Natural Hazards 93:393-409

Sharma RK, Shrestha DG (2016) Climate perceptions of local communities validated through scientific signals in Sikkim Himalaya, India. Environmental Monitoring and Assessment 188:578 [e-publication ahead of print, doi: 10.1007/s10661-016-5582-y]

Sherpa SF, Shrestha M, Eakin H, Boone CG (2019) Cryospheric hazards and risk perceptions in the Sagarmatha (Mt. Everest) National Park and Buffer Zone, Nepal. Natural Hazards [e-publication ahead of print, doi: 10.1007/s11069-018-3560-0

Sherry J, Curtis A (2017) At the intersection of disaster risk and religion: interpretations and responses to the threat of Tsho Rolpa glacial lake. Environmental Hazards 16:314-329

Shove E, Pantzar M, Watson M (2012) The dynamics of social practice: everyday life and how it changes. SAGE, London

Shrestha AB, Devkota LP (2010) Climate change in the Eastern Himalayas: observed trends and model projections. Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 1, ICIMOD, Kathmandu, 13 pp

Shrestha AB, Wake CP, Dibb JE, Mayewski PA (2000) Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters. International Journal of Climatology 20:317-327

Shrestha UB, Gautam S, Bawa KS (2012) Widespread climate change in the Himalayas and associated changes in local ecosystems. PLoS ONE 7:e36741

Sikkim SDMA (2012) Multi-hazard risk and vulnerability assessment of North, East, West and South Sikkim. State Disaster Management Authority, Land Revenue and Disaster Management Department, Government of Sikkim, Gangtok, 258 pp

Sikkim SDMA (2015a) Sikkim state disaster management plan, vol. 1: DRR and mitigation plan. State Disaster Management Authority, Government of Sikkim, Gangtok, 97 pp

Sikkim SDMA (2015b) Sikkim state disaster management plan, vol. 2: state disaster response plan. State Disaster Management Authority, Government of Sikkim, Gangtok, 44 pp

Sikkim SDMA (2015c) Sikkim state disaster management plan, vol. 3: checklists, formats and resource database. State Disaster Management Authority, Government of Sikkim, Gangtok, 150 pp

Sikkim SDMA (2015d) Sikkim state disaster management plan, vol. 4: specific action plan for line departments and other non-governmental stakeholders. State Disaster Management Authority, Government of Sikkim, Gangtok, 288 pp

Singh D, Horton DE, Tsiang M, Haugen M, Ashfaq M, Mei R, Rastogi D, Johnson NC, Charland A, Rajaratnam B, Diffenbaugh NS (2014) Severe precipitation in northern India in June 2013: causes, historical context, and changes in probability [in: Explaining extremes of 2013 from a climate perspective]. Bulletin of the American Meteorological Society 95:S58-S61

Smadja J (1997) Une lecture du territoire et du paysage des Tamang de Salmé. In: Smadja J (ed) Histoire et devenir des paysages en Himalaya. CNRS, Paris, pp 197-235

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Global Environmental Change 16:282-292

Smith K, Petley DN (2009) *Environmental hazards: assessing risk and reducing disaster.* Routledge, London

Sovacool BK (2011) Hard and soft paths for climate change adaptation. Climate Policy 11:1177-1183

Srivastava S, Cooperrider DL (1999) *Appreciative management and leadership: the power of positive thought and action in organization.* Revised edition. Crown Custom, Brunswick

Stavros JM, Cooperrider DL, Kelley L (2007) SOAR: A new approach to strategic planning. In: P. Homan P, Devane T, Cady S (eds) The change handbook: the definitive resource on today's best methods for engaging whole systems. 2nd edition. Berrett-Koekler, San Francisco, pp 375-380

Stavros JM, Hinrichs G (2007) SOARing to new heights of strategic planning to execution. AI Practitioner: SOARing to high and engaging performance: an appreciative approach to strategy, pp 4-9

Stavros JM, Sutherland J (2003) The heart of appreciative strategy. AI Practitioner: Strategic inquiry > appreciative intent: Inspiration to SOAR: a new framework for strategic planning, pp 5-9

Stavros JM (2013) The generative nature of SOAR: applications, results and the new SOAR profile. AI Practitioner 15:7-30

Steffen W, Crutzen PJ, McNeill JR (2007) The Anthropocene: are humans now overwhelming the great forces of nature? Ambio 36:614-621

Steffen W, Rockström J, Richardson K, Lenton TM, Folke C, Liverman D, Summerhayes CP, Barnosky AD, Cornell SE, Crucifix M, Donges JF, Fetzer I, Lade SJ, Scheffer M, Winkelmann R, Schellnhuber HJ (2018) Trajectories of the Earth system in the Anthropocene. Proceedings of the National Academy of Sciences 115:8252-8259

Sudmeier-Rieux K, Jaquet S, Derron M-H, Jaboyedoff M, Devkota S (2012) A case study of coping strategies and landslides in two villages of Central-Eastern Nepal. Applied Geography 32:680-690

Syed FS, Giorgi F, Pal JS, King MP (2006) Effect of remote forcings on the winter precipitation of central southwest Asia part 1: observations. Theoretical and Applied Climatology 86:147-160

Syed FS, Giorgi F, Pal JS, Keay K (2010) Regional climate model simulation of winter climate over Central-Southwest Asia, with emphasis on NAO and ENSO effects. International Journal of Climatology 30:220-235

Tedeschi RG, Calhoun LG (1996) The posttraumatic growth inventory: measuring the positive legacy of trauma. Journal of Traumatic Stress 9: 455-471

Telwala Y, Brook BW, Manish K, Pandit MK (2013) Climate-induced elevational range shifts and increase in plant species richness in a Himalayan biodiversity epicentre. PLoS ONE 8: e57103

Theil H (1950) A rank-invariant method of linear and polynomial regression analysis, Part 3. Proceedings of Koninalijke Nederlandse Akademie van Wetenschatpen A 53:1397-1412

Thomalla F, Downing T, Spanger-Siegfried E, Han G, Rockström J (2006) Reducing hazard vulnerability: towards a common approach between disaster risk reduction and climate adaptation. Disasters 30:39-48

Thomas K, Hardy RD, Lazrus H, Mendez M, Orlove B, Rivera-Collazo I, Roberts JT, Rockman M, Warner BP, Winthrop R (2019) Explaining differential vulnerability to climate change: A social science review. WIREs Climate Change 10:e565.

Thornton TF, Manasfi N (2010) Adaptation - genuine and spurious: demystifying adaptation processes in relation to climate change. Environment and Society: Advances in Research 1:132-155

Tomaselli KG, Dyll L, Francis M (2008) “Self” and “other”: auto-reflexive and indigenous ethnography. In: Denzin NK, Lincoln YS, Smith LT (eds.) Handbook of critical and indigenous methodologies. Sage, Thousand Oaks, pp 347-372

Tournadre N (2005) L'aire linguistique tibétaine et ses divers dialectes. Lalies 25:7-56

Townshend I, Awosoga O, Kulig J, Fan H (2015) Social cohesion and resilience across communities that have experienced a disaster. Natural Hazards 76:913-938

TNN (2013) 4,120 missing post-Uttarakhand floods. The Times of India (Online), Dehradun, 17 September

TNN (2018) Floods in Kerala due to beef festival: BJP MLA. The Times of India (online), Vijayapura, 26 August

Trenberth KE, Dai A, Rasmussen RM, Parsons DB (2003) The changing character of precipitation. Bulletin of the American Meteorological Society 84:1205-1217

Turner BL (2010) Vulnerability and resilience: coalescing or paralleling approaches for sustainability science? Global Environmental Change 20:570-576

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A (2003) A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences 100:8074-8079

UN (2015) Transforming our world: The 2030 agenda for sustainable development. Sustainable Development Goals Knowledge Platform, United Nations <sustainabledevelopment.un.org/post2015/transformingourworld/publication> Accessed 6 November 2018

UNFCCC (2015) Adoption of the Paris Agreement. Conference of the Parties Twenty-first Session, Paris <sustainabledevelopment.un.org/frameworks/parisagreement> Accessed 6 November 2018

UNISDR (2007) Hyogo framework for action 2005-2015: Building the resilience of nations and communities to disasters. World Conference on Disaster Reduction, 18-22 January 2005, Kobe, Hyogo, Japan <www.unisdr.org/we/inform/publications/1037> Accessed 10 August 2017

UNISDR (2015) Sendai framework for disaster risk reduction 2015-2030. United Nations Office for Disaster Risk Reduction, Geneva, 32 pp

Utsumi N, Seto S, Kanae S, Maeda EE, Oki T (2011) Does higher surface temperature intensify extreme precipitation? Geophysical Research Letters 38:L16708

Uttarakhand SDMA (2015) Sikkim state disaster management plan. State Disaster Management Authority, Government of Uttarakhand, Dehradun, 162 pp

Varnes DJ (1978) Slope movement: types and processes. In: Schuster RL, Krizek RJ (eds) Landslides: analysis and control. Transportation Research Board Special Report 176. National Academy Press, Washington, DC, pp 11–33

Vellore RK, Kaplan ML, Krishnan R, Lewis JM, Sabade S, Deshpande N, Singh BB, Madhura RK, Rama Rao MVS (2016) Monsoon-extratropical circulation interactions in Himalayan extreme rainfall. Climate Dynamics 46:3517-3546

Venton P, La Trobe S (2008) *Linking climate change adaptation and disaster risk reduction.* Tearfund, Teddington

Walder JS, Costa JE (1996) Outburst floods from glacier-dammed lakes: the effect of mode of lake drainage on flood magnitude. Earth Surface Processes and Landforms 21:701-723

Walder JS, Driedger CL (1995) Frequent outburst floods from South Tahoma Glacier, Mount Rainier, USA: relation to debris flows, meteorological origin, and implications for subglacial hydrology. Journal of Glaciology 41:1-10

Walder JS, Fountain AG (1997) Glacier generated floods. In: Destructive water: water-caused natural disasters, their abatement and control. In: Proceedings of the International Conference on Destructive Water, Anaheim. IAHS Publication No. 239, pp 107-113

Walker B, Gunderson L, Kinzig A, Folke C, Carpenter SR, Schultz L (2006) A handful of heuristics and some propositions for understanding resilience in social-ecological systems. Ecology and Society 11:13

Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social-ecological systems. Ecology and Society 9:5

Warburton J, Fenn CR (1994) Unusual flood events from an Alpine glacier: observations and deductions on generating mechanisms. Journal of Glaciology 40:176-186

Watanabe T, Byers AC, Somos-Valenzuela MA, McKinney DC (2016) The need for community involvement in glacial lake field research: The case of Imja glacial lake, Khumbu, Nepal Himalaya. In: Singh RB, Schickhoff U, Mal S (eds) Climate change, glacier response, and vegetation dynamics in the Himalaya. Springer, Cham, pp 235-250

Wenger E (1998) *Communities of practice: learning, meaning and identity.* Cambridge University Press, Cambridge

Westra S, Alexander LV, Zwiers FW (2013) Global increasing trends in annual maximum daily precipitation. Journal of Climate 26:3904-3918

Westra S, Fowler HJ, Evans JP, Alexander LV, Berg P, Johnson F, Kendon EJ, Lenderink G, Roberts NM (2014) Future changes to the intensity and frequency of short-duration extreme rainfall. Reviews of Geophysics 52:522–555

Whalley WB (1984) Rockfalls. In: Brunsden D, Prior DD (eds) Slope instability. Wiley, New York, pp 217-256

Wieczorek GF (1996) Landslide triggering mechanisms. In: Turner AK, Schuster RL (eds) Landslides: investigation and mitigation. Transportation Research Board Special Report 247. National Academy Press, Washington, DC, pp 76-90

Wieczorek GF, Morgan BA, Campbell RH (2000) Debris flow hazards in the Blue Ridge of Central Virginia. Environmental and Engineering Geoscience 6:3-23

Wisner B, Blaikie P, Cannon T, Davis I (2003) At risk: natural hazards, people, vulnerability, and disasters. 2nd edition. Routledge, London

Worni R, Huggel C, Stoffel M (2013) Glacial lakes in the Indian Himalayas – from an area-wide glacial lake inventory to on-site and modeling based risk assessment of critical glacial lakes. Science of the Total Environment 468-469:S71-S84

Wu J, Xu Y, Gao XJ (2017) Projected changes in mean and extreme climates over Hindu Kush Himalayan region by 21 CMIP models. Advances in Climate Change Research 8:176-184

Xu J, Grumbine E (2014) Integrating local hybrid knowledge and state support for climate change adaptation in the Asian Highlands. Climatic Change 124:93-104

Xu Y, Knudby A, Ho HC, Shen Y, Liu Y (2017) Warming over the Tibetan Plateau in the last 55 years based on area-weighted average temperature. Regional Environmental Change 17:2339-2347

Yadav RR, Park W-K, Singh J, Dubey B (2014) Do the western Himalayas defy global warming? Geophysical Research Letters 31:L17201

Yan L, Liu X (2014) Has climatic warming over the Tibetan Plateau paused or continued in recent years? Journal of Earth, Ocean and Atmospheric Sciences 1:13-28

Yohe G, Tol RSJ (2002) Indicators for social and economic coping capacity - moving toward a working definition of adaptive capacity. Global Environmental Change 12:25-40

Zhan Y-J, Ren G-Y, Shrestha AB, Rajbhandari R, Ren Y-Y, Sanjay J, Xu Y, Sun X-B, You Q-L, Wang S (2017) Changes in extreme precipitation events over the Hindu Kush Himalayan region during 1961-2012. Advances in Climate Change Research 8:166-175

Appendix 1A: Summary of SRES greenhouse gas emissions scenarios

Socio-economic conditions	***Special Report on Emissions Scenarios (SRES) greenhouse gas emissions scenario***						
	A1 *globally rapid economic growth*				**A2** *regionally focused economic growth*	**B1** *globally environ-mentally sustainable economic growth*	**B2** *locally environ-mentally sustainable economic growth*
	A1C*	**A1G***	**A1B**	**A1T**			
Population growth	low	low	low	low	high	low	medium
GDP growth	very high	very high	very high	very high	medium	high	medium
Energy use	very high	very high	very high	high	high	low	medium
Land use changes	low-medium	low-medium	low	low	medium/ high	high	medium
*Resource availability***	high	high	medium	medium	low	low	medium
Pace and direction of technological change favouring	rapid coal	rapid oil and gas	rapid balanced	rapid non-fossil fuels	slow regionally oriented	medium efficiency and dematerial-isation	medium "dynamics as usual"
Projected average global surface temperature rise until 2100	**1.4 - 6.4 °C**				**2.0 - 5.4 °C**	**1.1 - 2.9 °C**	**1.4 - 3.8 °C**

*A1C and A12G may be combined into a single fossil fuel-intensive **A1FI** group.
**This represents the availability of conventional and unconventional oil and gas resources.

Source: IPCC (2000, p. 178), adapted slightly

Appendix 1B: Summary of representative pathways for greenhouse gas concentrations (RCPs)

Conditions	***Representative concentration pathway (RCP)***			
	RCP 2.6	**RCP 4.5**	**RCP 6.0**	**RCP 8.5**
Radiative forcing value in the year 2100 (Wm^{-2})	2.6	4.6	6.0	8.5
Timing (years) of peaking of global greenhouse gas emissions (followed by decline)	2010-2020	around 2040	around 2080	continue to rise beyond 2100
Projected global surface temperature rise by 2081-2100 (mean and *likely* range)	**1.0°C (0.3 – 1.7 °C)**	**1.8°C (1.1 – 2.6 °C)**	**2.2°C (1.4 – 3.1 °C)**	**3.7°C (2.6 - 4.8 °C)**

Source: Based on IPCC (2013)

Appendix 2A: Schedule for in-depth community interviews

Preliminary Information
Village ………………………………. Name of interviewee …………………………………… Age ……….. Gender ………
Ethnicity ……………………………… (General / Scheduled Tribe / Scheduled Caste / Other Backward Class)
Educational qualifications ………………………… Household size (workers and dependants) …………………
Annual household income ………………….. Land holding (agricultural and other) …………………………………
Occupation of interviewee and family members, and any comments on seasonality of occupations
……
Details of dwelling and ancillary buildings (site, building material) …………………………………………….
……
Details of livestock (number, type) …………………………………………………………………………………………
Group memberships (collective / self help group / governmental institution / committee)
……

Part A: Environmental change

1. **Have you noticed any changes in weather patterns since your childhood?**

Season	Precipitation change (amount, form, intensity (including frequency of extremes), timing, and variability)	Temperature change (including intensity and frequency of extremes, timing, and variability)
Summer (May-Jun)		
Monsoon (Jul-Sep)		
Post-Monsoon (Oct-Nov)		
Winter (Dec-Feb)		
Spring (Mar-Apr)		
Overall		
Additional remarks		

1.1. If so, are you particularly concerned about any of those changes?

2. **Have your natural surroundings changed since your childhood? If so, how and why?**

Prompt keywords: mountain slopes (sediment/vegetation cover, stability), streams (course, discharge), snow cover (seasonal snowlines, snow depths), glaciers (length, thickness), vegetation (composition, extent, treelines, flowering seasons)

2.1. Are you particularly concerned about any of those changes?

Part B: Social change

3. **Has your village changed since your childhood? If so, how and why?**

Prompt keywords: Infrastructure (mobility/transport, communication, electricity, water, health, sanitation, education, banking and insurance); livelihood options/opportunities and preferences; local politics; social beliefs, attitudes, norms, customs and traditions

4. **What are the different things that people do for a living in your village?**

4.1. How do those occupations change over the seasons?

4.2. What are the occupations that people in your village have stopped engaging in, started engaging in, or started engaging in differently since your childhood?

5. **How is your life different from the lives lived by your parents and grandparents? In what respects is your life better and in what respects is it worse?**

Part C: Hazard, risk and resilience

6. Have you ever been harmed or felt threatened by the weather, the mountains, or any stream or lake?

6.1. Does your environment currently pose any risks to your life, everyday activities, or livelihood?

7. What are the things about yourself, your family, your community, and your culture that make you feel weak or strong in the face of any risk from the environment?

8. Are any individuals or households in the village considerably more or less vulnerable than you?

8.1. Do you think your gender, occupation, and social background affect your vulnerability?

9. Do you think your family, your community, and your government need to be prepared to face disasters (e.g. adverse impacts of intense rain, flash floods, landslides and debris flows)?

10. How well do you think your household and community are prepared to respond to, attenuate, and recover from disasters?

10.1. As regards preparedness for immediate response, are there any critical resources that your family does not have access to?

Prompt keywords: Emergency response plan, first aid and rescue equipment, disaster response training/experience, reliable telecommunications during disaster, safe drinking water during and immediately after disaster, emergency food stockpiles, community-level response coordination mechanism

10.2. As regards preparedness for long-term recovery, are there any critical resources that your family does not have access to?

Prompt keywords: Bank savings, insurance (life, crop, livestock), assets outside village, skills/education useful for alternative employment and livelihood diversification

11. How well do you think government agencies are prepared to respond to and attenuate disasters, and to help communities such as yours recover from disasters?

11.1. Are there any critical resources that they do not seem to have?

12. Can you think of any specific household-, community-, or government-level actions or practices that have helped or might help in protecting and improving lives and livelihoods in the face of dangerous environmental changes or disasters?

12.1. What resources (materials, skills, etc.) does your household, community, or government need to be able to undertake those actions or practices?

Appendix 2B: Outlines for focus group discussions and participatory exercises

2B1. Focus group discussion and participatory exercises – I

Participants: 6-8 (mixed-gender, mixed-class)

Objectives	Tools
To gain a preliminary understanding of the social and environmental setting	• Unstructured discussion on the social set-up and history of the community • Unstructured discussion on participants' understandings of, and everyday interactions with, their physical environment • Group exercise in which participants will view the village landscape from a vantage point and describe the physical and cultural features (and relationships among them) that they think play an important role in their lives
To record local spatial knowledge of geophysical hazards and lives and livelihood resources exposed to those hazards	• Participatory mapping: (i) Using a handheld GPS device to map risk zones and exposed human lives and livelihood resources (e.g. buildings, livestock, farmland, tree stands) for each hazard, as perceived/identified by participants on walks through and around their village; (ii) Making participants observe the village landscape from a vantage point and asking them to visualise and spatially depict on a two-dimensional surface any risks they associate with mountain slopes, watercourses, glaciers and glacial debris, etc. (materials: sticks and stones on soft ground, coloured markers on paper)
To roughly assess the potential impacts and costs (economic and socio-cultural) associated with hypothetical disaster events in perceived high-risk zones	• Discussion based on participant-generated hypothetical disaster scenarios informed by participatory mapping exercises
To document memories of past disasters	• Structured discussion on each disaster event remembered (see schedule below)
To obtain feedback on research questions and interview schedule	• Point-by-point discussion

Schedule for discussion on memories of past disasters

1. *Disaster type, date*
2. *Sequence of events*
3. *Community impacts (casualties, fatalities, homelessness, livelihood losses, infrastructural damage and connectivity loss) and costs (economic and socio-cultural)*
4. *Social (income-, caste/ethnicity-, occupation-, gender-, and age-based) and spatial (site-related) variations in community impacts*
5. *Immediate responses of community and local government*
6. *Challenges faced in search, rescue and evacuation (esp. logistical/coordination-related)*
7. *Disaster recovery and adaptation measures taken at community level*
8. *Disaster recovery, adaptation and livelihood support measures taken by government*
9. *Any monetary compensation received from government/insurance firms*
10. *Challenges faced in recovery and adaptation (including relocation)*
11. *Social (income-, caste/ethnicity-, occupation-, and gender-based) and spatial (site-related) variations in recovery and adaptation*
12. *Lessons learnt*

2B2. Focus group discussion and participatory exercises – II

Participants: 6-8 (well-informed community leaders, including at least two women and at least three members of elected village-level self-government body)

Objectives	Tools
To know what measures are already in place for reducing disaster risk, supporting adaptation, and enhancing resilience at the community and local government levels and how efficacious the community perceives them to be	• Group exercise in which participants will be asked to collectively list all existing measures/practices and then rate them by efficacy on a scale of 1 to 10 (using beans, beads, or marbles) • Discussion on efficacy ratings, particularly the strengths and weaknesses of the most and least efficacious measures
To enable a rapid community-based assessment of critical infrastructure associated with vulnerability/resilience	• Structured discussion on critical infrastructure (see schedule below)
To learn about planning-related, managerial, technical, and financial constraints on community adaptive capacity	• Group exercise in which participants will be asked to collectively list as many constraints as they can think of, and then rate them by importance on a scale of 1 to 10 (using beans, beads, or marbles) • Brainstorming session to generate ideas for overcoming the key constraints
To identify potentially feasible non-structural and small-scale structural interventions that might help in reducing disaster risk, supporting adaptation, and enduringly enhancing resilience in the context of livelihoods	• Brainstorming session to generate a list of potentially feasible interventions • Discussion on the benefits and costs of each suggested intervention • Group exercise in which participants will be asked to collectively rank the suggested interventions in order of priority

Schedule for discussion on critical infrastructure associated with vulnerability/resilience

Parameter	*Assessment: comments and rating on scale of 1-10 (0=non-existent, 10=excellent)*	
Mobile phone connectivity		
Access to mobile phone Internet		
Access to electricity		
Access to radio		
Access to television		
Road connectivity		
Emergency access to helicopter services		
Access to health services		
Access to education		
Government support and training schemes for alternative livelihoods		
Access to banking		
Access to insurance		
Other		

Appendix 2C: Objectives of elite interviews with government officials

D = district administration
S = state-level government agencies
N = national-level (federal) government agencies
Sc = national-level scientific agencies

Objectives	*Relevant levels of government*
To know what measures are already in place for reducing disaster risk, supporting adaptation, and enhancing resilience at the local and state government levels and how efficacious administrators perceive them to be	**D, S**
To enable a rapid assessment of critical infrastructure associated with vulnerability/resilience from the standpoint of local administrators	**D**
To gain an appreciation of the legal, political, and policy-related factors that enable and limit community adaptive capacity	**N, S**
To learn about the scientific and technological factors that enable and limit community adaptive capacity	**N, S, Sc**
To understand the planning- and finance-related factors that enable and limit community adaptive capacity	**N, S, D**
To understand the managerial, logistical and coordination-related factors that enable and limit community adaptive capacity	**N, S, D**
To identify legislative and policy interventions that might help in reducing disaster risk, supporting adaptation, and enduringly enhancing resilience in the context of livelihoods	**N, S**
To identify economic and social planning-related interventions that might help in reducing disaster risk, supporting adaptation, and enduringly enhancing resilience in the context of livelihoods	**N, S, D**
To identify spatial and environmental planning-related interventions that might help in reducing disaster risk, supporting adaptation, and enduringly enhancing resilience in the context of livelihoods	**N, S, D**
To identify managerial, logistical, co-ordination-related and behavioural interventions that might help in reducing disaster risk, supporting adaptation, and enduringly enhancing resilience in the context of livelihoods	**N, S, D**
To identify potentially feasible technological and small-scale engineering-based interventions that might help in reducing disaster risk, supporting adaptation, and enduringly enhancing resilience in the context of livelihoods	**N, S, D**

Appendix 3: Participant information and consent

Information for participants

Project title: *Understanding and enhancing the adaptation and resilience of remote high-mountain communities to hydrometeorological extremes and associated geophysical hazards in a changing climate*
Research period: *2015-2016*
Name of researcher: *Vaibhav Kaul*
Designation: *Doctoral Researcher*
Institution*: Department of Geography, The University of Sheffield, Sheffield S10 2TN, United Kingdom*
Contact details: *Phone:………………………… (India), ………………………………. (UK), E-mail:………………………………*

What is the project about?
Intense rain commonly causes landslides on mountain slopes, flash floods along streams, and outburst floods from high, glacier-related lakes, which can be devastating to mountain communities such as yours. This project seeks to understand vulnerability, resilience and adaptation to such hazards in a changing climate. It will focus on two village communities in the Indian Himalayas (one in Uttarakhand and the other in Sikkim). What is learnt from the communities will be used to devise workable strategies for protecting lives and livelihoods not only in their villages but also in similar villages elsewhere.

What are its objectives?
The objectives of the project are:

- To compare community knowledge of changes and extremes in the environment (and associated risks) with "scientific" data
- To explore communities' understandings of their own vulnerability and resilience, especially as reflected in everyday practices
- To identify livelihood resources and practices most at risk and assess the costs associated with their potential loss
- To identify adaptive practices already in operation at community and local government levels
- To assess the environmental, economic, social, technological, and governance-related factors that limit and enable community adaptive capacity
- To recommend measures for managing disaster risk, supporting adaptation to climate change, and sustaining long-term resilience in the context of livelihoods.

Why am I being invited to take part in the project?
The objectives of the project can be met only if the researcher interacts with members of your community and learns about their everyday lives. You are being invited to participate because your knowledge about your environment, the risks and challenges it poses, and how your community deals with or adapts to those risks can help us develop strategies for building a safer future for mountain communities in the Himalayas and beyond.

How can I take part in the project?
You can take part by being interviewed for about 40 minutes about your everyday life, livelihood, community, and environment. You can also contribute to group discussions on the same themes, or even group activities such as drawing a map of your village with the researcher. Your responses will generally be audio- or video-recorded, but if you do not want that to happen, they can be recorded only as notes (written material).
Any person who is invited to take part in the research project is free to decline. Participants are free to withdraw from the study at any time over the next three months without giving any reasons for doing so.

How will my information be used?
Your personal information will remain confidential – it will not be shared with persons outside the research project. It will be stored securely and separately from any recordings, transcripts, and observation notes associated with you. All recordings, transcripts, and observation notes associated with you will be stored under a false name of your choice. Your responses may be quoted in any output of the research project, e.g. a thesis, report, article, book, book section, lecture, poster, or documentary film – you may choose to have either your real name or your false name used for this purpose. The false name will ensure that potentially problematic people cannot identify you when they become aware of something you said and they did not like.

What are the possible risks of taking part?
Interviews and any other research activities will take place at your home, community centre, workplace, or a location that you regularly visit as part of your normal lifestyle. Therefore, the study will not expose you to any physical risks other than those that are part and parcel of your everyday life.
You may be asked to discuss past experiences with disasters. You are strongly discouraged from taking part in the project if discussions on natural hazards, disasters, and past disaster experiences might be a source of psychological discomfort for you.

Consent form

Project title: *Extreme Himalaya: Understanding and enhancing the adaptation and resilience of remote high-mountain communities to hydrometeorological extremes and associated geophysical hazards in a changing climate*

Research period: *2015-2016*
Name of researcher: *Vaibhav Kaul*
Designation: *Doctoral Researcher*
Institution*: Department of Geography, The University of Sheffield, Sheffield S10 2TN, United Kingdom*
Contact details: *Phone:………………………… (India), ………………………………. (UK), E-mail:…………………………….*

Please tick the appropriate box (Yes/No)

	Yes	No
Participation		
I have fully understood the contents of the information sheet on the research project.		
I have been allowed to freely ask questions about the research project.		
I wilfully agree to be interviewed by the researcher.		
I wilfully agree to participate in the group discussion/activity being conducted by the researcher.		
I wilfully agree to have my responses to the researcher's questions audio recorded.		
I wilfully agree to have my responses to the researcher's questions video recorded.		
I am aware that my participation in the research project is voluntary.		
I am aware that I am free to withdraw from the study at any time over the next three months without giving any reasons for doing so.		
I am aware that I will not be paid for my contribution to the research project.		
Use of information		
I am aware that my personal information will not be shared with persons outside the research project, and that it will be stored securely and separately from any recordings, transcripts, and observation notes associated with me.		
I am aware that all recordings, transcripts, and observation notes associated with me will be stored under a false name (alias) of my choice:…………………………………………………………………………………………………..		
I am aware that my responses may be quoted in any output of the research project, e.g. a thesis, report, article, book, book section, lecture, poster, or documentary film *Please choose one of the following two options:*		
I would like my real name used in the above.		
I would NOT like my real name to be used in the above. I would like my false name to be used in the above.		

……………………………	……………………………	……………………………
Name of participant	Signature	Date
……………………………	……………………………	……………………………
Name of researcher	Signature	Date
……………………………	……………………………	……………………………
Name of witness (if required)	*Signature*	*Date*

Appendix 4A: Observed and projected temperature changes for selected parts of South Asia

Appendix 4A.1. Temperature changes observed in selected parts of South Asia over the past few decades

S No	Published work	Observation period (data source)	Region (study site to which it is relevant)	Climatological indicator	Observed decadal trend (significance, where available)
1	Ren et al. (2017)	1951-2014 (LSAT-V1.1: China Meteorological Administration)	Hindu Kush - Himalaya (UM, ULC)	Mean annual temperature	+0.195°C ($p<0.05$)
2	Shrestha et al. (2012)	1982-2006 (Global Historical Climatology Network v. 2 and Climate Anomaly Monitoring System: Climate Prediction Center, USA)	Himalaya (UM, ULC)	Mean annual temperature	+0.6°C ($p<0.01$)
				Mean DJF (December-February) temperature	+0.7°C ($p<0.01$)
3	Gautam et al. (2010)	1979-2007 (Microwave Sounding Unit on NOAA satellites)	Western Himalaya (UM)	Mean annual tropospheric temperature	+0.26°C (±0.09 °C) ($p<0.01$)
			Hindu Kush		+0.20°C (±0.08 °C) ($p<0.05$)
			Eastern Himalaya (ULC)		+0.18°C (±0.08 °C) ($p<0.05$)
			Western Himalaya	Mean May tropospheric temperature	+0.67°C (±0.33 °C) ($p<0.1$)
			Hindu Kush		+0.39°C (±0.28 °C) ($p=0.17$)
			Eastern Himalaya		+0.34°C (±0.23 °C) ($p=0.17$)
4	Kothawale et al. (2010)	1970-2005 (India Meteorological Department)	Western Himalaya (UM)	No. of cold days (max temp ≤10th percentile) during MAM (March-May)	-2.1 days ($p\leq0.05$)
			Northeast India (ULC)		-1.3 days ($p>0.05$)
			Western Himalaya	No. of cold nights (min temp ≤10th percentile) during MAM	-2.7 days ($p\leq0.05$)
			Northeast India		-2.2 days ($p\leq0.05$)
5	Xu et al. (2017)	1961-2015 (China Meteorological Administration)	Tibetan Plateau (ULC)	Mean annual temperature (area-weighted)	+0.35°C ($p<0.01$)
				Mean DJF (December-February) temperature (area-weighted)	+0.44°C ($p<0.01$)
				Mean MAM (March-May) temperature (area-weighted)	+0.30°C ($p<0.01$)
				Mean JJA (June-August) temperature (area-weighted)	+0.30°C ($p<0.01$)
				Mean SON (September-November) temperature (area-weighted)	+0.38°C ($p<0.01$)
6	Yan and Liu (2014)	1961-2012 (China Meteorological Data Sharing Service System)	Tibetan Plateau (TP) (altitude >2,000 m	Mean annual temp	+0.32°C ($p<0.01$)
			Tibetan Plateau (TP) (altitude >3,000 m)		+0.33°C ($p\leq0.01$)
			Tibetan Plateau (TP) (altitude >4,000 m)		+0.36°C ($p\leq0.01$)
			TP (>2,000 m)	Mean DJF temp	+0.47°C
			TP (>3,000 m)		+0.49°C
			TP (>4,000 m)		+0.57°C
			TP (>2,000 m)	Mean MAM temp	+0.24°C
			TP (>3,000 m)		+0.26°C
			TP (>4,000 m)		+0.29°C
			TP (>2,000 m)	Mean JJA temp	+0.26°C
			TP (>3,000 m)		+0.27°C
			TP (>4,000 m)		+0.25°C
			TP (>2,000 m)	Mean SON temp	+0.32°C
			TP (>3,000 m)		+0.33°C
			TP (>4,000 m)		+0.36°C

			TP (>2,000 m)	Mean annual minimum temp	+0.43°C (p≤0.01)
			TP (>3,000 m)		+0.43°C (p≤0.01)
			TP (>4,000 m)		+0.47°C (p≤0.01)
			TP (>2,000 m)	Mean DJF min temp	+0.59°C
			TP (>3,000 m)		+0.60°C
			TP (>4,000 m)		+0.70°C
			TP (>2,000 m)	Mean MAM min temp	+0.37°C
			TP (>3,000 m)		+0.39°C
			TP (>4,000 m)		+0.42°C
			TP (>2,000 m)	Mean JJA min temp	+0.35°C
			TP (>3,000 m)		+0.35°C
			TP (>4,000 m)		+0.34°C
			TP (>2,000 m)	Mean SON min temp	+0.40°C
			TP (>3,000 m)		+0.40°C
			TP (>4,000 m)		+0.44°C
			Tibetan Plateau (ULC)	Annual no. of cold nights (min temp ≤10th percentile)	-5.89 days (p≤0.01)
				Annual no. of cold days (max temp ≤10th percentile)	-3.58 days (p≤0.01)
				Annual no. of warm nights (min temp ≥90th percentile)	+5.14 days (p≤0.01)
				Annual no. of warm days (max temp ≥90th percentile)	+3.15 days (p≤0.01)
				Annual max daily max temp	+0.25°C (p≤0.01)
				Annual max daily min temp	+0.28°C (p≤0.01)
				Annual min daily max temp	+0.28°C (p≤0.01)
				Annual min daily min temp	+0.60°C (p≤0.01)
				Annual no. of frost days (when min temp <0°C)	-4.65 days (p≤0.01)
				Annual no. of warm days (when max temp >15°C)	+3.22 days (p≤0.01)
				Growing season length (period in a year when daily min temp consistently remains >0°C)	+5.47 days (p≤0.01)
7	Shrestha and Devkota (2010)	1970-2000 (CRU TS2.0)	Eastern Himalaya (altitude <1,000 m)	Mean annual temp	+0.1°C
			Eastern Himalaya (ULC) (1,000-4,000 m)		+0.2°C
			Eastern Himalaya (ULC) (>4,000 m)		+0.4°C
			EH (<1,000 m)	Mean DJF temp	+0.3°C
			EH (1,000-4,000 m)		+0.3°C
			EH (>4,000 m)		+0.6°C
			EH (<1,000 m)	Mean MAM temp	±0.0°C
			EH (1,000-4,000 m)		+0.2°C
			EH (>4,000 m)		+0.4°C
			EH (<1,000 m)	Mean JJA temp	-0.1°C
			EH (1,000-4,000 m)		-0.1°C
			EH (>4,000 m)		+0.2°C
			EH (<1,000 m)	Mean SON temp	+0.2°C
			EH (1,000-4,000 m)		+0.2°C
			EH (>4,000 m)		+0.3°C
8	Rathore et al. (2013, India Meteorological Department)	1951-2010 (India Meteorological Department)	Uttarakhand (UM)	Mean annual temp	-0.1°C (p>0.05)
			Sikkim (ULC)		+0.5°C (p≤0.05)
			Uttarakhand	Mean DJF temp	+0.1°C (p>0.05)
			Sikkim		+0.5°C (p≤0.05)
			Uttarakhand	Mean MMA temp	-0.2°C (p>0.05)
			Sikkim		+0.5°C (p≤0.05)
			Uttarakhand	Mean JJAS temp	-0.2°C (p≤0.05)
			Sikkim		+0.5°C (p≤0.05)
			Uttarakhand	Mean ON temp	+0.1°C (p>0.05)
			Sikkim		+0.4°C (p≤0.05)
			Uttarakhand	Mean annual max temp	+0.2°C (p≤0.05)
			Sikkim		+0.2°C (p≤0.05)
			Uttarakhand	Mean DJF max temp	+0.2°C (p≤0.05)
			Sikkim		+0.2°C (p>0.05)
			Uttarakhand	Mean MAM max temp	±0.0°C
			Sikkim		+0.3°C (p≤0.05)

			Uttarakhand	Mean JJAS max temp	+0.1°C ($p>0.05$)
			Sikkim		+0.3°C ($p\leq0.05$)
			Uttarakhand	Mean ON max temp	+0.3°C ($p\leq0.05$)
			Sikkim		+0.1°C ($p>0.05$)
			Uttarakhand	Mean annual min temp	-0.3°C ($p\leq0.05$)
			Sikkim		+0.7°C ($p\leq0.05$)
			Uttarakhand	Mean DJF min temp	±0.0°C
			Sikkim		+0.8°C ($p\leq0.05$)
			Uttarakhand	Mean MAM min temp	-0.3°C ($p\leq0.05$)
			Sikkim		+0.7°C ($p\leq0.05$)
			Uttarakhand	Mean JJAS min temp	-0.4°C ($p\leq0.05$)
			Sikkim		+0.6°C ($p\leq0.05$)
			Uttarakhand	Mean ON min temp	-0.1°C ($p>0.05$)
			Sikkim		+0.8°C ($p\leq0.05$)

Appendix 4A.2. Temperature changes projected for selected parts of South Asia over the 21st century

S No	Published work	Region (study site to which it is relevant)	Climatological indicator	Baseline period	Projection period	Climate change scenario	Projected change	Modelling framework
1	Chaturvedi et al. (2012)	India (UM, ULC)	Mean annual temp	1961-1990	2067-2097	SRES A1B	+3.2°C	CMIP3 19-model ensemble mean
				1961-1990	2070-2099	RCP2.6	+1.5°C	CMIP5 18-model ensemble mean
						RCP4.5	+2.4°C	
						RCP6.0	+2.8°C	
						RCP 8.0	+4.3°C	
2	Krishna Kumar et al. (2011b)	India (UM, ULC)	Mean annual temp	1961-1990	2041-2070	SRES A1B	+2.9°C	PRECIS with lateral boundary conditions from QUMP simulation Q0
					2071-2098		+4.1°C	
					2041-2070		+2.5°C	PRECIS with lateral boundary conditions from QUMP simulation Q1
					2071-2098		+3.5°C	
					2041-2070		+3.2°C	PRECIS with lateral boundary conditions from QUMP simulation Q14
					2071-2098		+4.3°C	
			Mean JF temp		2041-2070		+3.5°C	PRECIS Q0
					2071-2098		+4.6°C	
					2041-2070		+3.0°C	PRECIS Q1
					2071-2098		+4.0°C	
					2041-2070		+3.4°C	PRECIS Q14
					2071-2098		+4.4°C	
			Mean MAM temp		2041-2070		+2.9°C	PRECIS Q0
					2071-2098		+4.1°C	
					2041-2070		+2.5°C	PRECIS Q1
					2071-2098		+3.7°C	
					2041-2070		+3.4°C	PRECIS Q14
					2071-2098		+4.3°C	
			Mean JJAS temp		2041-2070		+2.3°C	PRECIS Q0
					2071-2098		+3.5°C	
					2041-2070		+2.0°C	PRECIS Q1
					2071-2098		+2.8°C	
					2041-2070		+2.6°C	PRECIS Q14
					2071-2098		+3.8°C	
			Mean OND temp		2041-2070		+3.0°C	PRECIS Q0
					2071-2098		+4.4°C	
					2041-2070		+3.0°C	PRECIS Q1
					2071-2098		+4.2°C	
					2041-2070		+3.7°C	PRECIS Q14
					2071-2098		+4.6°C	
3	Rupa Kumar et al. (2006)	India (UM, ULC)	Mean annual temp	1961-1990	2071-2100	SRES A2	+4.1°C	PRECIS with lateral boundary conditions from HadAM3H simulations
						SRES B2	+2.9°C	
			Mean JF temp			SRES A2	+4.8°C	
						SRES B2	+3.3°C	

			Mean MAM temp			SRES A2	+3.7°C	
						SRES B2	+2.2°C	
			Mean JJAS temp			SRES A2	+3.5°C	
						SRES B2	+2.7°C	
			Mean OND temp			SRES A2	+4.7°C	
						SRES B2	+3.5°C	
4	Wu et al. (2017)	HKH (Hindu Kush – Himalaya) (UM, ULC)	Annual maximum of daily maximum temperature	1976-2005	2036-2065	RCP4.5	+2.1°C	CMIP5 21-model ensemble mean
					2066-2095		+2.7°C	
					2036-2065	RCP 8.5	+2.7°C	
					2066-2095		+4.8°C	
			Annual minimum of daily minimum temperature		2036-2065	RCP4.5	+2.2°C	
					2066-2095		+2.9°C	
					2036-2065	RCP 8.5	+2.9°C	
					2066-2095		+5.3°C	
5	Sanjay et al. (2017)	HKH1 (NW Himalaya) (UM)	Mean JJAS temp	1976-2005	2036-2065	RCP 4.5	+2.0°C	CORDEX multi-RCM ensemble mean
							+2.6°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+2.6°C	CORDEX multi-RCM ensemble mean
							+3.3°C	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+2.7°C	CORDEX multi-RCM ensemble mean
							+3.3°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+4.9°C	CORDEX multi-RCM ensemble mean
							+5.7°C	CMIP5 multi-AOGCM ensemble mean
		HKH2 (Central Himalaya) (UM, ULC)			2036-2065	RCP 4.5	+1.7°C	CORDEX multi-RCM ensemble mean
							+2.1°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+2.2°C	CORDEX multi-RCM ensemble mean
							+2.7°C	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+2.3°C	CORDEX multi-RCM ensemble mean
							+2.7°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+4.3°C	CORDEX multi-RCM ensemble mean
							+4.7°C	CMIP5 multi-AOGCM ensemble mean
		HKH3 (Far Eastern Himalaya) (ULC)			2036-2065	RCP 4.5	+1.7°C	CORDEX multi-RCM ensemble mean
							+2.0°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+2.2°C	CORDEX multi-RCM ensemble mean
							+2.5°C	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+2.3°C	CORDEX multi-RCM ensemble mean
							+2.5°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+4.2°C	CORDEX multi-RCM ensemble mean
							+4.4°C	CMIP5 multi-AOGCM ensemble mean
	Sanjay et al. (2017)	HKH1 (UM)	Mean DJF temp	1976-2005	2036-2065	RCP 4.5	+2.3°C	CORDEX multi-RCM ensemble mean
							+2.1°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+3.1°C	CORDEX multi-RCM ensemble mean
							+3.0°C	CMIP5 multi-AOGCM ensemble mean

					2036-2065	RCP 8.5	+3.2°C	CORDEX multi-RCM ensemble mean
							+3.0°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+5.4°C	CORDEX multi-RCM ensemble mean
							+5.1°C	CMIP5 multi-AOGCM ensemble mean
		HKH2 (UM, ULC)			2036-2065	RCP 4.5	+2.4°C	CORDEX multi-RCM ensemble mean
							+2.7°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+3.3°C	CORDEX multi-RCM ensemble mean
							+3.6°C	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+3.3°C	CORDEX multi-RCM ensemble mean
							+3.4°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+6.0°C	CORDEX multi-RCM ensemble mean
							+5.8°C	CMIP5 multi-AOGCM ensemble mean
		HKH3 (ULC)			2036-2065	RCP 4.5	+2.4°C	CORDEX multi-RCM ensemble mean
							+2.5°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+3.1°C	CORDEX multi-RCM ensemble mean
							+3.3°C	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+3.2°C	CORDEX multi-RCM ensemble mean
							+3.2°C	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+5.6°C	CORDEX multi-RCM ensemble mean
							+5.4°C	CMIP5 multi-AOGCM ensemble mean
6	Kulkarni et al. (2013)	Central Himalaya (UM)	Mean annual temp	1961-1990	2011-2040	SRES A1B	+1.6°C	PRECIS with lateral boundary conditions from QUMP simulations Q0, Q1, Q14
					2041-2070		+3.2°C	
					2071-2098		+4.3°C	
		Eastern Himalaya (ULC)			2011-2040		+1.4°C	
					2041-2070		+2.9°C	
					2071-2098		+4.1°C	
7	Shrestha and Devkota (2010)	Eastern Himalaya (ULC)	Mean annual temp	1961-1990	2071-2100	SRES A2	+4.3°C	PRECIS
						SRES B2	+2.9°C	
			Mean DJF temp			SRES A2	+5.3°C	
						SRES B2	+3.5°C	
			Mean MAM temp			SRES A2	+3.8°C	
						SRES B2	+2.6°C	
			Mean JJAS temp			SRES A2	+3.8°C	
						SRES B2	+2.8°C	
			Mean SON temp			SRES A2	+4.3°C	
						SRES B2	+2.5°C	
8	Bal et al. (2016)	Uttar P (UM)	Mean annual max temp	1975-2005	2035-2065	SRES A1B	+2.5°C	PRECIS with lateral boundary conditions from QUMP simulations Q0, Q1, Q5, Q7, Q11, Q13
					2065-2095		+3.9°C	
		Himachal P (UM)			2035-2065		+2.4°C	
					2065-2095		+3.5°C	
		Sikkim (ULC)			2035-2065		+2.3°C	
					2065-2095		+3.9°C	
		Uttar P (UM)	Mean annual min temp		2035-2065		+2.5°C	
					2065-2095		+3.9°C	
		Himachal P (UM)			2035-2065		+2.6°C	
					2065-2095		+3.8°C	
		Sikkim (ULC)			2035-2065		+2.4°C	
					2065-2095		+3.8°C	

9	Rao et al. (2018)	Rudraprayag District, Uttarakhand (RDU) (UM)	Mean annual max temp	1961-1990	2021-2050	SRES A1B	+2.2°C	PRECIS
		Uttarkashi District, Uttarakhand (UDU) (UM)					+2.2°C	
		Chamoli District, Uttarakhand (CDU) (UM)					+2.1°C	
		RDU (UM)	Mean annual min temp				+2.3°C	
		UDU (UM)					+2.2°C	
		CDU (UM)					+2.4°C	
		RDU (UM)	No. of DJF days when min temp falls below normal by ≥4°C				-0.2	
		UDU (UM)					-1.8	
		CDU (UM)					-1.7	
		RDU (UM)	No. of DJF frost days (when min temp <0°C)				-1.57	
		UDU (UM)					-3.27	
		CDU (UM)					±0.0	
10	Nepal Climate Vulnerability Study Team (2009)	Garhwal (grid cell covering region corresponding to UM)	Mean annual temp	1970-1999	2030-2039	SRES A2	+1.6°C	15-GCM ensemble mean
					2060-2069		+3.2°C	
					2090-2099		+5.3°C	
		North Sikkim (grid cell corresponding to ULC)			2030-2039		+1.5°C	
					2060-2069		+3.0°C	
					2090-2099		+4.8°C	
		Garhwal (UM)	Mean DJF temp		2030-2039		+1.8°C	
					2060-2069		+3.4°C	
					2090-2099		+5.7°C	
		North Sikkim (ULC)			2030-2039		+1.7°C	
					2060-2069		+3.4°C	
					2090-2099		+5.7°C	
		Garhwal (UM)	Mean MAM temp		2030-2039		+2.0°C	
					2060-2069		+3.3°C	
					2090-2099		+5.7°C	
		North Sikkim (ULC)			2030-2039		+1.6°C	
					2060-2069		+3.1°C	
					2090-2099		+5.6°C	
		Garhwal (UM)	Mean JJA temp		2030-2039		+1.5°C	
					2060-2069		+3.0°C	
					2090-2099		+4.6°C	
		North Sikkim (ULC)			2030-2039		+1.3°C	
					2060-2069		+2.5°C	
					2090-2099		+4.3°C	
		Garhwal (UM)	Mean SON temp		2030-2039		+1.3°C	
					2060-2069		+2.9°C	
					2090-2099		+4.8°C	
		North Sikkim (ULC)			2030-2039		+1.3°C	
					2060-2069		+2.8°C	
					2090-2099		+4.5°C	
		Garhwal (UM)	Annual no. of hot days (max temp ≥95th percentile)		2060-2069		+20%	
					2090-2099		+29%	
		North Sikkim (ULC)			2060-2069		+19%	
					2090-2099		+32%	
		Garhwal (UM)	No. of hot days (max temp ≥95th percentile) in DJF		2060-2069		+42%	
					2090-2099		+72%	
		North Sikkim (ULC)			2060-2069		+33%	
					2090-2099		+65%	
		Garhwal (UM)	No. of hot days (max temp ≥95th percentile) in MAM		2060-2069		+25%	
					2090-2099		+41%	
		North Sikkim (ULC)			2060-2069		+25%	
					2090-2099		+51%	

		Garhwal (UM)	No. of hot days (max temp ≥95th percentile) in JJAS		2060-2069		+34%	
					2090-2099		+49%	
		North Sikkim (ULC)			2060-2069		+49%	
					2090-2099		+53%	
		Garhwal (UM)	No. of hot days (max temp ≥95th percentile) in SON		2060-2069		+22%	
					2090-2099		+37%	
		North Sikkim (ULC)			2060-2069		+25%	
					2090-2099		+43%	
		Garhwal (UM)	Annual no. of hot nights (min temp ≥95th percentile)		2060-2069		+21%	
					2090-2099		+29%	
		North Sikkim (ULC)			2060-2069		+22%	
					2090-2099		+32%	
		Garhwal (UM)	No. of hot nights (min temp ≥95th percentile) in DJF		2060-2069		+24%	
					2090-2099		+52%	
		North Sikkim (ULC)			2060-2069		+30%	
					2090-2099		+58%	
		Garhwal (UM)	No. of hot nights (min temp ≥95th percentile) in MAM		2060-2069		+28%	
					2090-2099		+46%	
		North Sikkim (ULC)			2060-2069		+25%	
					2090-2099		+46%	
		Garhwal (UM)	No. of hot nights (min temp ≥95th percentile) in JJAS		2060-2069		+46%	
					2090-2099		+72%	
		North Sikkim (ULC)			2060-2069		+58%	
					2090-2099		+76%	
		Garhwal (UM)	No. of hot nights (min temp ≥95th percentile) in SON		2060-2069		+22%	
					2090-2099		+38%	
		North Sikkim (ULC)			2060-2069		+23%	
					2090-2099		+37%	

Appendix 4B. Observed and projected precipitation changes for selected parts of South Asia

Appendix 4B.1. Precipitation changes observed in selected parts of the Himalaya over the past few decades

S No	Published work	Observation period (data source)	Region (study site to which it is relevant)	Climatological indicator	Observed decadal trend (significance, where available)
1	Ren et al. (2017)	1961-2013 (CGP1.0: China Meteorological Administration)	Hindu Kush-Himalaya (UM, ULC)	Total annual precipitation	+5.28% (p≤0.01)
2	Zhan et al. (2017)	1961-2012 (GLDP-V1.0 multiple datasets)	Hindu Kush-Himalaya (UM, ULC)	Total annual precipitation	+3.53% (p≤0.01)
				Annual prec received as amounts ≥90th percentile of wet-day prec	+6.16% (p≤0.01)
				Annual number of wet days (≥1 mm prec)	+2.69% (p≤0.01)
				Annual number of wet days with prec ≥90th percentile	+5.10% (p≤0.01)
				Mean daily prec intensity for wet days with prec ≥90th percentile	+1.32% (p≤0.05)
				Maximum one-day precipitation	+2.14% (p≤0.01)
				Maximum three-day precipitation	+2.26% (p≤0.01)
				Maximum five-day precipitation	+2.34% (p≤0.01)
3	Rathore et al. (2013, India Meteorological Department)	1951-2010 (India Meteorological Department)	Uttarakhand	Annual precipitation	-10.7 mm (p>0.05)
			Sikkim		-31.2 mm (p>0.05)
			Uttarakhand	DJF (winter) precipitation	-0.1 mm (p>0.05)
			Sikkim		-1.2 mm (p>0.05)
			Uttarakhand	MAM (early summer) precipitation	+8.6 mm (p>0.05)
			Sikkim		-8.3 mm (p>0.05)
			Uttarakhand	JJAS (monsoon) precipitation	-14.5 mm (p>0.05)
			Sikkim		-13.6 mm (p>0.05)
			Uttarakhand	ON (post-monsoon) precipitation	-6.3 mm (p>0.05)
			Sikkim		-1.1 mm (p>0.05)
			Uttarakhand	January precipitation	-5.3 mm (p>0.05)
			Sikkim		-3.0 mm (p>0.05)
			Uttarakhand	February precipitation	+4.9 mm (p>0.05)
			Sikkim		+0.4 mm (p>0.05)
			Uttarakhand	March precipitation	-1.0 mm (p>0.05)
			Sikkim		+2.6 mm (p>0.05)
			Uttarakhand	April precipitation	+4.0 mm (p>0.05)
			Sikkim		+35.1 mm (p≤0.05)
			Uttarakhand	May precipitation	+6.2 mm (p>0.05)
			Sikkim		-31.6 mm (p>0.05)
			Uttarakhand	June precipitation	+6.0 mm (p>0.05)
			Sikkim		-1.9 mm (p>0.05)
			Uttarakhand	July precipitation	-17.1 mm (p>0.05)
			Sikkim		-11.7 mm (p>0.05)
			Uttarakhand	August precipitation	-4.1 mm (p>0.05)
			Sikkim		+1.2 mm (p>0.05)
			Uttarakhand	September precipitation	+3.9 mm (p>0.05)
			Sikkim		-14.5 mm (p>0.05)
			Uttarakhand	October precipitation	-4.2 mm (p>0.05)
			Sikkim		-0.1 mm (p>0.05)
			Uttarakhand	November precipitation	±0 mm
			Sikkim		+2.1 mm (p>0.05)
			Uttarakhand	December precipitation	-0.1 mm (p>0.05)
			Sikkim		-0.5 mm (p>0.05)

Appendix 4B.2. Precipitation changes projected for selected parts of South Asia over the 21st century

S No	Published work	Region (study site to which it is relevant)	Climatological indicator	Baseline period	Projection period	Climate change scenario	Projected change	Modelling framework
1	Chaturvedi et al. (2012)	India (UM, ULC)	Annual precipitation	1961-1990	2070-2099	RCP2.6	+6%	CMIP5 18-model ensemble mean
						RCP4.5	+10%	
						RCP6.0	+9%	
						RCP 8.0	+14%	
2	Krishna Kumar et al. (2011b)	India (UM, ULC)	Annual precipitation	1961-1990	2041-2070	SRES A1B	+11.5%	PRECIS with lateral boundary conditions from QUMP simulation Q0
					2071-2098		+15.4%	
					2041-2070		+8.3%	PRECIS with lateral boundary conditions from QUMP simulation Q14
					2071-2098		+11.5%	
			JJAS precipitation		2041-2070		+11.5%	PRECIS Q0
					2071-2098		+16.5%	
					2041-2070		+8.8%	PRECIS Q14
					2071-2098		+8.9%	
3	Rupa Kumar et al. (2006)	India (UM, ULC)	Annual precipitation	1961-1990	2071-2100	SRES A2	+23.4%	PRECIS with lateral boundary conditions from HadAM3H simulations
						SRES B2	+17.8%	
			JJAS precipitation			SRES A2	+18.6%	
						SRES B2	+14.8%	
4	Wu et al. (2017)	HKH (Hindu Kush – Himalaya) (UM, ULC)	Annual prec received as amounts ≥95th percentile of wet-day prec	1976-2005	2036-2065	RCP4.5	+23.5%	CMIP5 21-model ensemble mean
					2066-2095		+32.4%	
					2036-2065	RCP 8.5	+31.8%	
					2066-2095		+57.8%	
			Maximum five-day precipitation		2036-2065	RCP4.5	+8.1%	
					2066-2095		+11.2%	
					2036-2065	RCP 8.5	+11.2%	
					2066-2095		+20.2%	
5	Sanjay et al. (2017)	HKH1 (NW Himalaya) (UM)	JJAS precipitation	1976-2005	2036-2065	RCP 4.5	-0.1%	CORDEX multi-RCM ensemble mean
							+0.8%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+3.5%	CORDEX multi-RCM ensemble mean
							-0.3%	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+3.7%	CORDEX multi-RCM ensemble mean
							+3.6%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+3.9%	CORDEX multi-RCM ensemble mean
							+5.0%	CMIP5 multi-AOGCM ensemble mean
		HKH2 (Central Himalaya) (UM, ULC)			2036-2065	RCP 4.5	+4.4%	CORDEX multi-RCM ensemble mean
							+6.7%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+10.5%	CORDEX multi-RCM ensemble mean
							+11.8%	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+9.1%	CORDEX multi-RCM ensemble mean
							+10.7%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+19.1%	CORDEX multi-RCM ensemble mean
							+19.1%	CMIP5 multi-AOGCM ensemble mean

		HKH3 (Far Eastern Himalaya) (ULC)			2036-2065	RCP 4.5	+6.8%	CORDEX multi-RCM ensemble mean
							+4.6%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+10.4%	CORDEX multi-RCM ensemble mean
							+7.3%	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+10.2%	CORDEX multi-RCM ensemble mean
							+5.7%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+22.6%	CORDEX multi-RCM ensemble mean
							+9.7%	CMIP5 multi-AOGCM ensemble mean
	Sanjay et al. (2017)	HKH1 (UM)	DJF precipitation	1976-2005	2036-2065	RCP 4.5	+7.0%	CORDEX multi-RCM ensemble mean
							+1.0%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+14.1%	CORDEX multi-RCM ensemble mean
							+6.2%	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+12.8%	CORDEX multi-RCM ensemble mean
							+5.1%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+12.9%	CORDEX multi-RCM ensemble mean
							+6.9%	CMIP5 multi-AOGCM ensemble mean
		HKH2 (UM, ULC)			2036-2065	RCP 4.5	-0.7%	CORDEX multi-RCM ensemble mean
							-7.7%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+1.5%	CORDEX multi-RCM ensemble mean
							-0.7%	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	-1.3%	CORDEX multi-RCM ensemble mean
							-8.5%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		-8.8%	CORDEX multi-RCM ensemble mean
							-8.1%	CMIP5 multi-AOGCM ensemble mean
		HKH3 (ULC)			2036-2065	RCP 4.5	+3.1%	CORDEX multi-RCM ensemble mean
							+2.1%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+3.7%	CORDEX multi-RCM ensemble mean
							+5.5%	CMIP5 multi-AOGCM ensemble mean
					2036-2065	RCP 8.5	+0.9%	CORDEX multi-RCM ensemble mean
							+0.7%	CMIP5 multi-AOGCM ensemble mean
					2066-2095		+0.6%	CORDEX multi-RCM ensemble mean
							+6.0%	CMIP5 multi-AOGCM ensemble mean
6	Kulkarni et al. (2013)	Central Himalaya (UM)	JJAS precipitation	1961-1990	2011-2040	SRES A1B	+3.6%	PRECIS with lateral boundary conditions from QUMP simulations Q0, Q1, Q14
					2041-2070		+13.4%	
					2071-2098		+23.6%	
		Eastern Himalaya (ULC)			2011-2040		+0.9%	
					2041-2070		+6.5%	
					2071-2098		+12.4%	

7	Shrestha and Devkota (2010)	Eastern Himalaya (ULC)	Annual precipitation	1961-1990	2071-2100	SRES A2	+34%	PRECIS
						SRES B2	+13%	
			DJF precipitation			SRES A2	+35%	
						SRES B2	+23%	
			MAM precipitation			SRES A2	+46%	
						SRES B2	+8%	
			JJAS precipitation			SRES A2	+28%	
						SRES B2	+17%	
			ON precipitation			SRES A2	+18%	
						SRES B2	+12%	
8	Bal et al. (2016)	Uttar P (UM)	Annual precipitation	1975-2005	2035-2065	SRES A1B	+8.2%	PRECIS with lateral boundary conditions from QUMP simulations Q0, Q1, Q5, Q7, Q11, Q13
					2065-2095		+10.9%	
		Himachal P (UM)			2035-2065		+10.2%	
					2065-2095		+25.5%	
		Sikkim (ULC)			2035-2065		+6.1%	
					2065-2095		+6.2%	
9	Rao et al. (2018)	Rudraprayag District, Uttarakhand (RDU) (UM)	Annual precipitation	1961-1990	2021-2050	SRES A1B	+7.9%	PRECIS
		Uttarkashi District, Uttarakhand (UDU) (UM)					+11.3%	
		Chamoli District, Uttarakhand (CDU) (UM)					+7.0%	
		RDU (UM)	Annual prec received as amounts ≥99th percentile of wet-day prec				+15.2%	
		UDU (UM)					+19.7%	
		CDU (UM)					+10.8%	
		RDU (UM)	Annual no. of events with >100 mm prec over 3 days				+20.9%	
		UDU (UM)					+43.9%	
		CDU (UM)					+20.1%	
10	Nepal Climate Vulnerability Study Team (2009)	Garhwal (grid cell covering region corresponding to UM)	Annual precipitation	1970-1999	2030-2039	SRES A2	-3% (-20, +10)	15-GCM ensemble mean
					2060-2069		±0% (-14, +28)	
					2090-2099		+1% (-24, +34)	
		North Sikkim (grid cell corresponding to ULC)			2030-2039		±0% (-29, +19)	
					2060-2069		+2% (-33, +60)	
					2090-2099		+14% (-36, +111)	
		Garhwal (UM)	DJF precipitation		2030-2039		-13% (-36, +34)	
					2060-2069		-6% (-52, +19)	
					2090-2099		-22% (-46, +32)	
		North Sikkim (ULC)			2030-2039		-10% (-36, +14)	
					2060-2069		-13% (-35, +19)	
					2090-2099		-10% (-47, +11)	

		Garhwal (UM)	MAM precipitation		2030-2039		-13% (-35, +2)	
					2060-2069		-15% (-28, +19)	
					2090-2099		-22% (-41, +15)	
		North Sikkim (ULC)			2030-2039		+4% (-29, +34)	
					2060-2069		+1% (-46, +14)	
					2090-2099		+7% (-65, +43)	
		Garhwal (UM)	JJA precipitation		2030-2039		-1% (-27, +51)	
					2060-2069		+1% (-17, +177)	
					2090-2099		+1% (-53, +189)	
		North Sikkim (ULC)			2030-2039		+3% (-29, +43)	
					2060-2069		+5% (-18, +133)	
					2090-2099		+19% (-26, +225)	
		Garhwal (UM)	SON precipitation		2030-2039		-4% (-28, +71)	
					2060-2069		+9% (-26, +48)	
					2090-2099		+3% (-35, +59)	
		North Sikkim (ULC)			2030-2039		±0% (-23, +28)	
					2060-2069		±0% (-24, +33)	
					2090-2099		+20% (-40, +73)	
		Garhwal (UM)	Proportion of DJF prec falling as heavy events		2060-2069		-2% (-20, +12)	
					2090-2099		+3% (-16, +8)	
		North Sikkim (ULC)			2060-2069		-2% (-11, +1)	
					2090-2099		-4% (-10, +5)	
		Garhwal (UM)	Proportion of JJA prec falling as heavy events		2060-2069		+4% (-7, +16)	
					2090-2099		+5% (-2, +25)	
		North Sikkim (ULC)			2060-2069		+5% (-7, +28)	
					2090-2099		+15% (-18, +40)	
		Garhwal (UM)	Max one-day precipitation during DJF		2060-2069		±0 mm (-9, +7)	
					2090-2099		±0 mm (-5, +4)	
		North Sikkim (ULC)			2060-2069		±0 mm (-9, +3)	
					2090-2099		-1 mm (-5, +4)	
		Garhwal (UM)	Max one-day precipitation during JJA		2060-2069		+2 mm (-7, +7)	
					2090-2099		+4 mm (-3, +12)	
		North Sikkim (ULC)			2060-2069		+2 mm (-1, +49)	
					2090-2099		+6 mm (-3, +65)	

		Garhwal (UM)	Max one-day precipitation during SON		2060-2069		±0 mm (-7, +12)	
					2090-2099		+5 mm (-14, +14)	
		North Sikkim (ULC)			2060-2069		+2 mm (-1, +12)	
					2090-2099		+6 mm (+0, +30)	
		Garhwal (UM)	Max five-day precipitation during DJF		2060-2069		-6 mm (-15, +11)	
					2090-2099		-5 mm (-15, +10)	
		North Sikkim (ULC)			2060-2069		±0 mm (-15, +6)	
					2090-2099		-2 mm (-15, +3)	
		Garhwal (UM)	Max five-day precipitation during JJA		2060-2069		+4 mm (-19, +16)	
					2090-2099		+9 mm (-12, +25)	
		North Sikkim (ULC)			2060-2069		+4 mm (-3, +145)	
					2090-2099		+22 mm (-2, +190)	
		Garhwal (UM)	Max five-day precipitation during SON		2060-2069		+4 mm (-12, +23)	
					2090-2099		+7 mm (-38, +25)	
		North Sikkim (ULC)			2060-2069		+5 mm (-4, +26)	
					2090-2099		+17 mm (-10, +69)	

Appendix 4C: Summer Monsoon Precipitation: Summaries of Trends

Appendix 4C.1. Darjeeling, Eastern Himalaya (1901-1996): June-September

S. No.	Index	Trend																								
		June** (n=92)					July* (n=88)					August (n=86)					September (n=85)					JJAS* (n=81)				
		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T	
		β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p
1	Monthly precipitation *(seasonal for JJAS)*	-1.15	0.02	-0.99	-1.50		-1.40	0.05	-1.21	-1.61		-1.91	0.11	-1.70	-2.52		-0.56	0.01	+0.05	+0.08		-6.18	0.17	-5.69	-4.01	
2	Wet days	-0.02	0.02	-0.01	-1.33		-0.02	0.06	0.00	-1.63		-0.03	0.05	-0.01	-1.46		-0.01	0.01	0.00	-0.24		-0.07	0.07	-0.06	-2.08	
3	Mean daily precipitation intensity	-0.03	0.01	-0.02	-1.01		-0.03	0.02	-0.02	-1.04		-0.05	0.09	-0.05	-2.45		+0.00	5E-05	+0.01	+0.35		-0.05	0.11	-0.04	-2.88	
4	Maximum one-day precipitation	-0.15	0.00	-0.16	-0.98		-0.15	0.01	-0.14	-0.98		-0.32	0.06	-0.22	-1.64		-0.03	0.00	+0.07	+0.36		-0.44	0.03	-0.41	-2.66	
5	Maximum three-day precipitation	-0.23	0.00	-0.28	-0.87		-0.44	0.04	-0.35	-1.61		-0.76	0.15	-0.67	-3.04		-0.22	0.00	+0.04	+0.08		-0.91	0.06	-0.93	-3.09	
6	Maximum five-day precipitation	-0.54	0.02	-0.41	-1.36		-0.39	0.02	-0.36	-1.29		-1.03	0.17	-0.83	-3.26		-0.48	0.01	-0.08	-0.19		-1.05	0.06	-1.04	-2.80	
7	Maximum wet spell length	-0.03	0.04	-0.03	-1.72		-0.06	0.05	-0.06	-2.25		-0.02	0.01	-0.01	-0.88		-0.00	0.00	0.00	-0.12		-0.05	0.02	-0.05	-1.15	
8	Mean wet spell length	-0.01	0.00	-0.01	-1.59		-0.03	0.01	-0.03	-2.15		-0.02	0.01	-0.02	-1.47		-0.01	0.01	0.00	-0.33		-0.02	0.05	-0.02	-2.19	
9	Precipitation during longest wet spell	-1.37	0.03	-1.31	-2.04		-1.77	0.05	-2.02	-2.32		-1.68	0.07	-1.60	-2.31		-0.37	0.01	-0.04	-0.13		-2.93	0.09	-2.62	-2.35	
10	Days with precipitation ≥80th p	-0.01	0.00	0.00	-0.57		-0.01	0.02	0.00	-1.35		-0.02	0.07	-0.02	-2.16		-0.00	0.00	0.00	+0.25		-0.06	0.11	-0.06	-3.01	
11	Days with precipitation ≥90th p	-0.01	0.01	0.00	-0.75		-0.02	0.07	0.00	-2.07		-0.02	0.08	-0.02	-2.72		-0.00	4.8E-05	0.00	+0.32		-0.05	0.12	-0.05	-3.20	
12	Days with precipitation ≥95th p	-0.01	0.02	0.00	-1.40		-0.01	0.02	0.00	-0.87		-0.01	0.09	0.00	-2.56		-0.00	0.01	0.00	-0.23		-0.04	0.16	-0.04	-3.29	
13	Days with precipitation ≥99th p	-0.00	0.00	0.00	-0.49		-0.00	0.03	0.00	-1.74		-0.00	0.06	0.00	-2.23		-0.00	0.02	0.00	-0.79		-0.02	0.17	0.00	-3.53	
14	Total precipitation received as amounts ≥80th p	-0.72	0.01	-0.52	-0.79		-1.44	0.04	-1.36	-1.73		-1.85	0.11	-1.74	-2.74		-0.54	0.01	+0.03	+0.06		-5.64	0.15	-5.76	-3.67	
15	Total precipitation received as amounts ≥90th p	-0.67	0.01	-0.53	-0.84		-1.56	0.07	-1.32	-2.04		-1.65	0.12	-1.70	-3.14		-0.46	0.00	+0.05	+0.17		-5.26	0.15	-5.59	-3.70	
16	Total precipitation received as amounts ≥95th p	-0.81	0.01	-0.08	-1.09		-0.91	0.03	-0.19	-0.98		-1.31	0.11	-1.09	-2.47		-0.68	0.01	0.00	-0.26		-4.89	0.16	-4.57	-3.54	
17	Total precipitation received as amounts ≥99th p	-0.25	0.00	0.00	-0.57		-0.55	0.02	0.00	-1.68		-0.72	0.07	0.00	-2.47		-0.45	0.02	0.00	-0.82		-2.70	0.11	-1.96	-3.28	

Abbreviations and symbols: OLS: Ordinary Least Squares Regression, β: Slope, R^2: Coefficient of Determination, SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: ***Purple ≤ 0.001, Wine red ≤ 0.01, Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1.*** *1995 excluded due to potentially erroneous data (observations of >500 mm day^{-1} during 29-31 July) **Data for 1901-1999
Years for which data are missing: 1908 (A, S, JJAS), 1909 (J, J, A, S, JJAS), 1953 (S, JJAS), 1973 (J, J, A, S, JJAS), 1975 (JJAS), 1981 (July, A, S. JJAS), 1982 and 1983 (J, J, A, S, JJAS), 1984 (S), 1985 (J, J, A, JJAS), 1986 (S, JJAS), 1987 (J, J, A, S, JJAS), 1989 (JJAS), 1990 (A, S, JJAS), 1995 (July, JJAS), 1998 (June)

Appendix 4C.2. Darjeeling, Eastern Himalaya (various multi-decadal periods): July, August, June-September

S. No.	Index	Trend																	
		July						August						June-September					
		1901-1950 (n=49)			1951-1996* (n=39)			1901-1950 (n=48)			1951-1996 (n=38)			1901-1950 (n=48)			1951-1996* (n=33)		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p
1	Monthly/seasonal precipitation	-1.17	-0.48		-3.99	-1.74		-1.83	-0.93		-1.92	-1.06		-9.76	-2.36		-5.75	-1.72	
2	Wet days	0.00	+1.44		-0.09	-2.97		0.00	-0.01		0.00	-0.01		+0.04	+1.01		-0.25	-2.00	
3	Mean daily precipitation intensity	-0.08	-1.00		-0.04	-0.60		-0.05	-0.83		-0.06	-1.11		-0.12	-2.62		-0.01	-0.54	
4	Maximum one-day precipitation	-0.01	-0.03		-0.15	-0.31		-0.60	-1.71		+0.02	+0.06		-0.57	-1.47		-0.81	-1.78	
5	Maximum three-day precipitation	-0.00	-0.01		-0.43	-0,80		-1.22	-2.34		-0.32	-0.47		-0.74	-0.79		-0.97	-1.13	
6	Maximum five-day precipitation	+0.00	0.00		+0.30	+0.31		-1.45	-1.98		-0.79	-1.23		-0.86	-0.79		+0.24	+0.26	
7	Maximum wet spell length	0.00	-0.03		-0.20	-2.54		0.00	-0.30		0.00	+0.15		+0.04	+0.56		-0.12	-0.99	
8	Mean wet spell length	0.00	+0.76		-0.16	-3.22		-0.02	-0.69		0.00	-0.13		+0.01	+0.67		-0.07	-3.02	
9	Precipitation during longest wet spell	-0.64	-0.35		-5.07	-2.01		-1.35	-0.65		-2.82	-1.63		-2.19	-0.90		-1.76	-0.48	
10	Days with precipitation $\geq 80^{th}$ p	0.00	-0.30		-0.03	-1.10		-0.02	-1.11		0.00	-0.58		-0.14	-2.36		-0.06	-1.09	
11	Days with precipitation $\geq 90^{th}$ p	0.00	-0.96		0.00	-1.10		0.00	-1.36		0.00	-1.37		-0.08	-1.85		-0.03	-0.94	
12	Days with precipitation $\geq 95^{th}$ p	0.00	-0.84		0.00	-0.06		0.00	-1.46		0.00	-1.40		-0.07	-2.07		0.00	-0.25	
13	Days with precipitation $\geq 99^{th}$ p	0.00	-0.51		0.00	-1.30		0.00	-0.87		0.00	-0.83		0.00	-2.20		0.00	-1.75	
14	Total precipitation received as amounts $\geq 80^{th}$ p	-1.39	-0.80		-3.01	-1.21		-3.31	-1.73		-1.61	-0.88		-12.23	-2.64		-3.52	-1.13	
15	Total precipitation received as amounts $\geq 90^{th}$ p	-1.70	-1.08		-1.45	-0.87		-2.81	-1.83		-1.44	-1.31		-10.08	-2.30		-3.59	-0.88	
16	Total precipitation received as amounts $\geq 95^{th}$ p	-0.56	-0.86		0.00	-0.15		-2.28	-1.84		-0.48	-0.63		-8.43	-2.27		-2.64	-0.79	
17	Total precipitation received as amounts $\geq 99^{th}$ p	0.00	-0.39		0.00	-1.36		0.00	-1.23		0.00	-0.95		-3.63	-1.86		-1.39	-2.15	

Abbreviations and symbols: OLS: Ordinary Least Squares Regression, β: Slope, R^2: Coefficient of Determination, SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, ***Wine red ≤ 0.01, Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1****.*
Years for which data are missing:
1908 (A, JJAS), 1909 (J, A, JJAS), 1953 (JJAS), 1973 (J, A, JJAS), 1975 (JJAS), 1981 (J, A, JJAS), 1982 and 1983 (J, A, JJAS), 1985 (J, A, JJAS), 1986 (JJAS), 1987 (J, A, JJAS), 1989 (JJAS), 1990 (A, JJAS), 1995 (J, JJAS)
*1995 excluded due to potentially erroneous data (extreme observations of >500 mm day^{-1} during 29-31 July)

Appendix 4C.3. Darjeeling, Eastern Himalaya (various multi-decadal periods): June, September

S. No.	Index	Trend											
		June						September					
		1901-1950 (n=49)			1951-1999 (n=43)			1901-1950 (n=48)			1951-1996 (n=37)		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	P
1	Monthly precipitation	-3.20	-1.72		+0.01	0.00		-0.10	-0.06		-0.81	-0.33	
2	Wet days	0.00	+0.47		-0.05	-1.18		0.00	+0.83		0.00	-0.57	
3	Mean daily precipitation intensity	-0.13	-1.94		+0.08	+0.96		-0.04	-0.51		+0.02	+0.20	
4	Maximum one-day precipitation	-0.25	-0.42		+0.47	+1.00		+0.08	+0.17		-0.19	-0.20	
5	Maximum three-day precipitation	-0.93	-1.38		+0.75	+1.15		+0.40	+0.52		-0.84	-0.90	
6	Maximum five-day precipitation	-0.42	-0.47		+0.38	+0.49		-0.07	-0.07		-1.28	-0.73	
7	Maximum wet spell length	0.00	-0.49		-0.03	-0.85		+0.03	+0.97		-0.06	-1.34	
8	Mean wet spell length	-0.01	-0.44		-0.03	-1.17		0.01	+0.66		-0.03	-1.73	
9	Precipitation during longest wet spell	-2.27	-1.13		+0.85	+0.61		+0.77	+0.56		-0.95	-0.56	
10	Days with precipitation ≥80th p	-0.04	-1.62		0.00	-0.01		0.00	-0.20		0.00	-0.11	
11	Days with precipitation ≥90th p	0.00	-1.28		0.00	+0.85		0.00	-0.17		0.00	-0.04	
12	Days with precipitation ≥95th p	0.00	-1.14		0.00	+1.17		0.00	-0.46		0.00	-0.97	
13	Days with precipitation ≥99th p	0.00	-0.13		0.00	+1.15		0.00	-0.53		0.00	-0.97	
14	Total precipitation received as amounts ≥80th p	-2.74	-1.35		+0.77	+0.23		-0.69	-0.36		-1.06	-0.33	
15	Total precipitation received as amounts ≥90th p	-2.03	-1.12		+1.45	+0.86		0.00	0.00		-0.87	-0.38	
16	Total precipitation received as amounts ≥95th p	-0.52	-0.63		+0.05	+1.01		0.00	-0.39		-0.98	-0.99	
17	Total precipitation received as amounts ≥99th p	0.00	-0.22		0.00	+0.93		0.00	-0.71		0.00	-0.97	

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
*Colours denote significance levels: Purple ≤ 0.001, Wine red ≤ 0.01, **Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1**.*
Years for which data are missing: 1908 (S), 1909 (J), 1953 (S), 1973 (J), 1981 (S), 1982 and 1983 (J, S), 1984 (S), 1985 (J), 1986 (S), 1987 (J, S), 1990 (S), 1998 (J)

Appendix 4C.4. Gangtok, Eastern Himalaya (1985-2014): June, July, August, September, June-September

S. No.	Index	Trend																								
		June (n=30)					July (n=30)					August (n=30)					September (n=30)					JJAS (n=30)				
		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T	
		β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p
1	Monthly precipitation *(seasonal for JJAS)*	+ 3.16	0.02	+ 4.74	+ 1.11		+ 0.61	0.00	+ 0.15	+ 0.14		+ 0.10	0.01	+ 0.51	+ 0.32		- 5.35	0.11	- 2.96	- 1.28		- 0.57	0.00	+ 2.71	+ 0.32	
2	Wet days	+ 0.05	0.04	+ 0.04	+ 1.07		- 0.05	0.11	0.00	- 1.59		+ 0.00	5.3E -05	0.00	+ 0.11		- 0.07	0.04	- 0.07	- 1.28		- 0.06	0.02	0.00	- 0.31	
3	Mean daily precipitation intensity	+ 0.09	0.01	+ 0.18	+ 0.93		+ 0.06	0.02	+ 0.01	+ 0.36		+ 0.04	0.01	+ 0.03	+ 0.29		- 0.15	0.08	- 0.08	- 0.82		+ 0.01	0.00	+ 0.03	+ 0.57	
4	Maximum one-day precipitation	+ 0.60	0.01	+ 0.65	+ 0.75		- 0.34	0.04	- 0.35	- 0.98		+ 0.43	0.06	+ 0.66	+ 1.53		- 0.65	0.04	- 0.33	- 0.75		- 0.39	0.01	- 0.40	- 0.79	
5	Maximum three-day precipitation	+ 0.77	0.01	+ 1.31	+ 0.75		- 0.43	0.02	- 0.23	- 0.32		- 0.10	0.00	- 0.24	- 0.34		- 1.56	0.06	- 1.24	- 1.14		- 1.46	0.04	- 1.63	- 1.57	
6	Maximum five-day precipitation	+ 0.60	0.00	+ 1.41	+ 0.93		+ 0.06	0.00	- 0.06	- 0.04		+ 0.48	0.01	+ 0.66	+ 0.96		- 1.17	0.02	- 0.69	- 0.43		- 2.05	0.05	- 1.89	- 1.46	
7	Maximum wet spell length	- 0.03	0.00	0.00	+ 0.07		- 0.13	0.03	- 0.09	- 0.70		+ 0.09	0.02	+ 0.07	+ 0.65		- 0.02	0.00	0.00	+ 0.22		- 0.40	0.05	- 0.35	- 1.39	
8	Mean wet spell length	- 0.04	0.00	+ 0.04	+ 1.13		- 0.17	0.03	0.00	- 1.24		+ 0.10	0.02	0.00	+ 0.52		- 0.14	0.06	- 0.05	- 1.68		- 0.06	0.01	- 0.03	- 0.46	
9	Precipitation during longest wet spell	- 2.77	0.01	- 1.23	- 0.25		- 0.67	0.00	- 1.15	- 0.18		+ 3.14	0.03	+ 3.96	+ 0.86		- 3.16	0.03	- 1.46	- 0.43		- 12.4	0.07	- 11.76	- 1.57	
10	Days with precipitation ≥80th p	+ 0.09	0.06	+ 0.10	+ 1.39		+ 0.10	0.15	+ 0.08	+ 2.14		+ 0.04	0.02	0.00	+ 0.61		- 0.07	0.06	- 0.06	- 1.16		+ 0.12	0.05	+ 0.13	+ 1.36	
11	Days with precipitation ≥90th p	+ 0.01	0.00	0.00	+ 0.61		+ 0.01	0.00	0.00	+ 0.16		- 0.02	0.01	0.00	- 0.24		- 0.09	0.14	- 0.05	- 1.53		- 0.01	0.00	0.00	0.00	
12	Days with precipitation ≥95th p	+ 0.01	0.00	0.00	+ 0.43		- 0.02	0.03	0.00	- 1.21		- 0.01	0.01	0.00	- 0.26		- 0.04	0.05	0.00	- 0.57		- 0.03	0.08	0.00	- 0.47	
13	Days with precipitation ≥99th p	+ 0.00	0.00	0.00	+ 0.58		- 0.01	0.04	0.00	- 1.26		+ 0.01	0.04	0.00	+ 1.18		- 0.02	0.06	0.00	- 1.17		- 0.00	0.00	0.00	- 0.21	
14	Total precipitation received as amounts ≥80th p	+ 4.28	0.03	+ 5.20	+ 1.36		+ 3.80	0.08	+ 4.05	+ 1.71		+ 1.70	0.02	+ 1.21	+ 0.71		- 5.16	0.09	- 3.58	- 1.46		+ 3.63	0.01	+ 5.50	+ 0.64	
15	Total precipitation received as amounts ≥90th p	+ 1.09	0.00	+ 2.79	+ 0.55		- 0.03	5E -06	- 0.35	- 0.23		- 0.35	0.00	+ 0.46	+ 0.04		- 5.46	0.13	- 2.96	- 1.39		- 1.22	0.00	+ 0.03	0.00	
16	Total precipitation received as amounts ≥95th p	+ 0.99	0.00	0.00	+ 0.49		- 1.76	0.04	- 1.94	- 1.07		- 0.45	0.00	0.00	+ 0.20		- 3.05	0.05	- 0.36	- 0.60		- 2.48	0.01	- 2.72	- 0.68	
17	Total precipitation received as amounts ≥99th p	+ 0.49	0.00	0.00	+ 0.60		- 1.35	0.04	0.00	- 1.19		+ 1.04	0.03	0.00	+ 1.08		- 1.72	0.07	0.00	- 1.24		- 0.60	0.00	0.00	- 0.27	

Abbreviations and symbols: OLS: Ordinary Least Squares Regression, β: Slope, R^2: Coefficient of Determination, SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, Wine red ≤ 0.01, ***Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1.***

Appendix 4C.5. Gangtok, Eastern Himalaya: (various periods): July, August, June-September

S. No.	Index	Trend																	
		July						August						June-September					
		1985-1999 (n=15)			2000-2014 (n=15)			1985-1999 (n=15)			2000-2014 (n=15)			1985-1999 (n=15)			2000-2014 (n=15)		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p
1	Monthly/seasonal precipitation	+ 0.58	0.00		+ 0.98	+ 0.59		+ 8.50	+ 0.89		- 6.64	- 0.49		+ 36.95	+ 1.68		+ 4.18	+ 0.20	
2	Wet days	0.00	+ 0.73		0.00	+ 0.41		0.00	+ 1.16		+ 0.14	+ 1.13		+ 0.29	+ 1.05		+ 0.08	+ 0.40	
3	Mean daily precipitation intensity	- 0.06	- 0.20		- 0.00	0.00		+ 0.19	+ 0.59		- 0.15	- 0.49		+ 0.25	+ 1.78		+ 0.04	+ 0.30	
4	Maximum one-day precipitation	- 0.77	- 0.79		- 0.72	- 0.59		- 0.10	0.00		+ 0.05	+ 0.10		+ 0.93	+ 0.49		+ 0.05	0.00	
5	Maximum three-day precipitation	- 1.62	- 0.69		+ 0.31	+ 0.10		+ 0.07	0.00		- 2.58	- 1.19		- 0.75	0.00		- 1.74	- 0.49	
6	Maximum five-day precipitation	- 3.03	- 1.39		+ 3.16	+ 1.88		+ 2.98	+ 0.69		- 0.90	- 0.30		+ 2.54	+ 0.49		- 2.09	- 0.79	
7	Maximum wet spell length	+ 0.14	+ 0.76		0.00	0.00		+ 0.09	+ 0.40		+ 0.20	+ 0.45		+ 1.89	+ 1.73		- 0.50	- 1.24	
8	Mean wet spell length	0.00	+ 0.67		0.00	+ 0.41		+ 0.17	+ 1.36		+ 0.33	+ 1.15		+ 0.55	+ 2.33		- 0.15	- 0.69	
9	Precipitation during longest wet spell	+ 4.58	+ 0.30		+ 2.20	0.00		+ 18.25	+ 1.88		- 0.40	0.00		+ 37.52	+ 1.19		- 21.88	- 1.58	
10	Days with precipitation ≥80th p	0.00	+ 0.41		+ 0.17	+ 1.32		0.00	+ 0.45		0.00	- 0.10		+ 0.60	+ 1.70		+ 0.11	+ 0.55	
11	Days with precipitation ≥90th p	0.00	0.00		+ 0.09	+ 1.14		0.00	- 0.20		0.00	- 0.67		+ 0.17	+ 0.85		+ 0.11	+ 0.30	
12	Days with precipitation ≥95th p	- 0.08	- 1.29		0.00	- 0.52		0.00	- 0.26		- 0.91	- 1.08		0.00	+ 0.10		0.00	- 0.15	
13	Days with precipitation ≥99th p	0.00	- 1.55		0.00	- 1.22		0.00	0.00		0.00	- 0.23		0.00	+ 1.04		0.00	0.00	
14	Total precipitation received as amounts ≥80th p	- 0.08	0.00		+ 7.13	+ 1.48		+ 4.88	+ 0.30		- 1.88	- 0.40		+ 29.01	+ 1.39		+ 14.18	+ 0.49	
15	Total precipitation received as amounts ≥90th p	- 0.35	- 0.10		+ 3.50	+ 0.79		- 0.34	0.00		- 5.18	- 0.59		+ 16.41	+ 0.89		+ 6.71	+ 0.30	
16	Total precipitation received as amounts ≥95th p	- 6.44	- 1.04		- 2.29	- 0.35		0.00	0.00		- 5.52	- 1.04		+ 4.59	+ 0.30		- 5.45	- 0.40	
17	Total precipitation received as amounts ≥99th p	0.00	- 1.35		0.00	- 1.14		0.00	0.00		0.00	- 0.34		+ 10.51	+ 1.00		0.00	0.00	

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, Wine red ≤ 0.01, ***Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1****.*

Appendix 4C.6. Mangan, Eastern Himalaya (2001-2015): June, July, August, September, June-September

S. No.	Index	Trend																								
		June (n=15)					July (n=15)					August (n=14)					September (n=14)					JJAS (n=13)				
		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T	
		β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p
1	Monthly precipitation *(seasonal for JJAS)*	+ 8.69	0.04	+ 5.11	+ 0.89		- 15.58	0.12	- 20.30	- 1.39		+ 2.61	0.00	+ 0.84	0.00		+ 3.02	0.00	- 2.98	- 0.33		- 3.08	0.00	+ 5.15	+ 0.06	
2	Wet days	- 0.19	0.07	- 0.17	- 0.45		- 0.13	0.03	- 0.17	- 0.91		- 0.14	0.03	- 0.13	- 0.44		- 0.28	0.14	- 0.25	- 1.44		- 0.76	0.15	- 0.96	- 1.29	
3	Mean daily precipitation intensity	+ 0.61	0.11	+ 0.47	+ 0.59		- 0.42	0.11	- 0.41	- 0.89		+ 0.26	0.03	+ 0.06	+ 0.22		+ 0.42	0.04	+ 0.07	+ 0.33		+ 0.15	0.03	+ 0.20	+ 0.31	
4	Maximum one-day precipitation	+ 1.72	0.02	+ 1.53	+ 0.40		- 0.48	0.00	+ 0.82	+ 0.20		+ 5.26	0.30	+ 4.43	+ 1.75		- 0.75	0.00	- 1.09	- 0.99		+ 1.55	0.02	+ 0.92	+ 0.31	
5	Maximum three-day precipitation	+ 0.14	7.9E-05	+ 3.21	+ 0.40		- 1.85	0.03	- 0.64	- 0.30		+ 8.05	0.21	+ 5.26	+ 1.20		- 0.75	0.00	- 3.32	- 1.20		+ 1.99	0.01	+ 1.00	- 0.18	
6	Maximum five-day precipitation	- 0.10	0.00	+ 0.55	+ 0.10		- 1.77	0.01	- 1.89	- 0.30		+ 13.74	0.26	+ 12.36	+ 1.53		+ 3.26	0.01	- 2.47	- 0.66		+ 6.22	0.07	+ 2.42	+ 0.06	
7	Maximum wet spell length	- 0.09	0.01	- 0.09	- 0.15		- 0.64	0.16	- 0.63	- 1.35		- 0.54	0.10	- 0.50	- 0.66		- 0.35	0.07	- 0.42	- 1.16		- 1.60	0.23	- 0.69	- 0.98	
8	Mean wet spell length	- 0.04	0.00	- 0.11	- 0.35		- 0.75	0.15	- 0.59	- 1.99		- 0.62	0.15	- 0.01	- 0.05		- 0.16	0.02	- 0.14	- 0.77		- 0.42	0.15	- 0.27	- 1.10	
9	Precipitation during longest wet spell	- 1.41	0.00	+ 2.38	+ 0.20		- 22.01	0.15	- 24.65	- 1.39		- 1.39	0.00	- 1.95	- 0.11		+ 0.31	2.8E-05	- 7.25	- 0.88		- 33.24	0.18	- 25.47	- 1.04	
10	Days with precipitation ≥80th p	+ 0.24	0.07	+ 0.30	+ 1.05		- 0.35	0.14	- 0.25	- 1.45		- 0.17	0.06	- 0.21	- 1.12		+ 0.04	0.00	0.00	0.00		- 0.09	0.00	+ 0.29	+ 0.43	
11	Days with precipitation ≥90th p	+ 0.15	0.06	+ 0.11	+ 0.81		- 0.21	0.09	0.00	- 0.15		+ 0.12	0.06	+ 0.11	+ 0.72		- 0.12	0.03	0.00	0.00		+ 0.17	0.02	+ 0.13	+ 0.49	
12	Days with precipitation ≥95th p	+ 0.14	0.12	0.00	+ 0.93		- 0.00	0.00	0.00	+ 0.31		+ 0.12	0.09	0.00	+ 0.92		+ 0.01	0.00	0.00	- 0.65		+ 0.24	0.07	+ 0.24	+ 0.74	
13	Days with precipitation ≥99th p	+ 0.02	0.01	0.00	+ 0.65		- 0.03	0.07	0.00	- 0.92		+ 0.09	0.29	0.00	+ 2.01		+ 0.02	0.01	0.00	- 0.15		+ 0.16	0.22	+ 0.00	+ 0.58	
14	Total precipitation received as amounts ≥80th p	+ 14.98	0.09	+ 14.02	+ 0.84		- 16.43	0.14	- 8.65	- 0.94		+ 5.78	0.02	+ 5.13	+ 0.33		+ 6.69	0.02	- 3.75	- 0.66		+ 14.44	0.02	+ 15.97	+ 0.18	
15	Total precipitation received as amounts ≥90th p	+ 12.79	0.08	+ 4.18	+ 0.50		- 11.17	0.09	+ 0.10	0.00		+ 14.21	0.12	+ 11.39	+ 0.93		+ 8.58	0.03	- 1.26	- 0.33		+ 23.30	0.08	+ 24.14	+ 0.67	

Abbreviations and symbols: OLS: Ordinary Least Squares Regression, β: Slope, R^2: Coefficient of Determination, SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, Wine red ≤ 0.01, ***Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1.***
Years for which data are missing: 2008 (S, JJAS), 2009 (A, JJAS)

Appendix 4C.7. Dehradun, Western Himalaya (1901-2014): June, July, August, September, June-September

S. No.	Index	Trend																								
		June (n=111)					July (n=112)					August (n=111)					September (n=112)					JJAS* (n=109)				
		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T		OLS		SE	M-K T	
		β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p	β	R^2	Q	Z	p
1	Monthly precipitation *(seasonal for JJAS)*	+1.05	0.04	+0.64	+1.85		+0.35	0.00	+0.30	+0.43		-0.06	7.7E-05	+0.14	+0.18		+0.47	0.01	+0.53	+1.09		+1.56	0.01	+1.48	+1.02	
2	Wet days	+0.03	0.04	+0.03	+1.86		+0.02	0.02	+0.02	+1.50		+0.01	0.01	0.00	+0.78		+0.02	0.02	+0.02	+1.18		+0.08	0.06	+0.08	+2.45	
3	Mean daily precipitation intensity	+0.04	0.01	+0.03	+1.14		-0.00	6.8E-05	-0.00	-0.00		-0.01	0.00	-0.00	-0.20		+0.00	0.00	+0.01	+0.33		-0.01	0.00	-0.0	-0.32	
4	Maximum one-day precipitation	+0.28	0.04	+0.16	+1.70		+0.11	0.00	-0.00	-0.01		-0.10	0.00	-0.03	-0.26		+0.09	0.01	+0.11	+0.98		+0.01	2E-05	-0.11	-0.73	
5	Maximum three-day precipitation	+0.62	0.05	+0.28	+2.05		+0.03	0.00	+0.02	+0.10		-0.25	0.01	-0.10	-0.42		+0.14	0.00	+0.13	+0.74		-0.20	0.00	-0.32	-1.20	
6	Maximum five-day precipitation	+0.70	0.04	0.00	+1.74		+0.28	0.01	+0.36	+1.31		-0.12	0.00	-0.08	-0.26		+0.19	0.00	0.00	+0.57		+0.14	0.00	-0.02	-0.03	
7	Maximum wet spell length	+0.01	0.02	0.00	+1.76		+0.01	0.00	0.00	+0.71		+0.02	0.02	+0.02	+1.67		+0.01	0.01	0.00	+0.84		+0.02	0.01	+0.03	+1.82	
8	Mean wet spell length	+0.00	0.02	+0.00	+1.58		+0.01	0.01	+0.01	+1.70		-0.00	1.6E-05	0.00	+0.66		+0.01	0.01	0.00	+0.29		+0.00	0.01	+0.00	+1.33	
9	Precipitation during longest wet spell	+0.75	0.04	+0.32	+1.95		+0.37	0.01	+0.50	+1.27		-0.36	0.00	+0.70	+1.40		+0.26	0.00	+0.11	+0.44		+0.54	0.00	+1.04	+1.75	
10	Days with precipitation ≥80th p	+0.01	0.02	+0.02	+1.72		+0.00	0.00	0.00	+0.37		-0.01	0.01	0.00	-0.50		+0.01	0.00	0.00	+0.58		+0.02	0.01	+0.02	+1.03	
11	Days with precipitation ≥90th p	+0.01	0.03	0.00	+1.24		+0.00	0.01	0.00	+1.14		+0.00	0.00	0.00	+0.58		+0.01	0.02	0.00	+1.46		+0.01	0.00	0.00	+0.52	
12	Days with precipitation ≥95th p	+0.01	0.03	0.00	+1.95		-0.00	2.5E-05	0.00	+0.21		+0.00	0.00	0.00	+0.78		+0.00	0.00	0.00	+0.47		+0.01	0.01	0.00	+0.92	
13	Days with precipitation ≥99th p	+0.00	0.02	0.00	+1.46		-0.00	0.01	0.00	-0.96		-0.00	0.01	0.00	-0.96		-0.00	0.00	0.00	+0.53		-0.00	0.01	0.00	-0.68	
14	Total precipitation received as amounts ≥80th p	+1.01	0.04	+0.60	+1.75		+0.13	0.00	+0.16	+0.27		-0.42	0.00	-0.14	-0.19		+0.35	0.00	+0.44	+0.95		+1.04	0.01	+0.94	+0.68	
15	Total precipitation received as amounts ≥90th p	+0.95	0.03	+0.47	+1.57		+0.27	0.00	+0.24	+0.44		-0.07	0.00	+0.20	+0.37		+0.42	0.01	+0.40	+1.21		+0.58	0.00	+0.77	+0.61	
16	Total precipitation received as amounts ≥95th p	+0.89	0.04	+0.06	+1.93		-0.06	0.00	0.00	+0.01		+0.07	0.00	0.00	+0.33		+0.14	0.00	0.00	+0.76		+0.57	0.00	+0.74	+0.67	
17	Total precipitation received as amounts ≥99th p	+0.59	0.03	0.00	+1.49		-0.17	0.00	0.00	-0.86		-0.39	0.02	0.00	-1.10		-0.10	0.00	0.00	+0.59		-0.44	0.00	0.00	-0.79	

Abbreviations and symbols: OLS: Ordinary Least Squares Regression, β: Slope, R^2: Coefficient of Determination, SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, Wine red ≤ 0.01, ***Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1****.*
Years for which data are missing: 1990 (June, JJAS), 1992 (J, J, A, S, JJAS), 2008 (J, J, A, S, JJAS), 2010 (A, JJAS)
*Data for 1901-2013

Appendix 4C.8. Dehradun, Western Himalaya (various multi-decadal periods): June

S. No.	Index	Trend for **June**																	
		1901-1950 (n=50)			1951-2000 (n=48)			1951-2014 (n=61)			1951-1980 (n=30)			1981-2014 (n=31)			2001-2014 (n=13)		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p
1	Monthly precipitation	+ 0.59	+ 0.57		+ 3.40	+ 2.79		+ 1.57	+ 1.68		+ 6.19	+ 2.57		+ 0.13	+ 0.02		- 2.16	- 0.43	
2	Wet days	+ 0.04	+ 0.65		+ 0.08	+ 1.79		+ 0.05	+ 1.43		+ 0.21	+ 2.09		0.00	+ 0.07		- 0.40	- 1.04	
3	Mean daily precipitation intensity	+ 0.07	+ 0.79		+ 0.21	+ 2.62		+ 0.11	+ 1.72		+ 0.33	+ 2.03		- 0.11	- 0.54		+ 0.37	+ 0.67	
4	Maximum one-day precipitation	+ 0.40	+ 1.47		+ 0.88	+ 2.18		+ 0.35	+ 1.44		+ 1.43	+ 1.53		- 0.43	- 0.58		+ 0.48	+ 0.31	
5	Maximum three-day precipitation	+ 0.11	+ 1.01		+ 1.60	+ 2.70		+ 0.93	+ 2.35		+ 1.38	+ 1.92		0.00	- 0.02		- 0.04	0.00	
6	Maximum five-day precipitation	0.00	+ 0.84		0.00	+ 1.38		0.00	+ 1.29		0.00	+ 1.27		0.00	+ 0.10		0.00	- 0.65	
7	Maximum wet spell length	0.00	+ 0.66		0.00	+ 1.04		0.00	+ 1.05		+ 0.10	+ 1.91		0.00	+ 0.34		- 0.17	- 1.19	
8	Mean wet spell length	+ 0.01	+ 1.04		+ 0.07	+ 0.64		+ 0.03	+ 0.52		+ 0.02	+ 1.32		+ 0.01	+ 0.22		- 0.07	- 1.16	
9	Precipitation during longest wet spell	+ 0.60	+ 1.24		+ 1.34	+ 2.19		+ 0.86	+ 2.24		+ 1.77	+ 1.75		+ 0.31	+ 0.17		- 0.75	- 0.06	
10	Days with precipitation ≥80th p	0.00	+ 0.71		+ 0.06	+ 1.74		0.00	+ 0.95		+ 0.17	+ 2.11		0.00	+ 0.10		0.00	- 0.32	
11	Days with precipitation ≥90th p	0.00	+ 0.65		+ 0.06	+ 2.24		+ 0.02	+ 1.47		+ 0.10	+ 2.07		0.00	+ 0.26		0.00	+ 0.51	
12	Days with precipitation ≥95th p	0.00	+ 1.15		+ 0.03	+ 2.50		0.00	+ 1.35		0.00	+ 1.66		0.00	- 0.60		0.00	+ 0.13	
13	Days with precipitation ≥99th p	0.00	- 0.37		0.00	+ 1.77		0.00	+ 1.25		0.00	+ 1.28		0.00	- 0.87		0.00	- 0.33	
14	Total precipitation received as amounts ≥80th p	+ 0.72	+ 0.60		+ 3.44	+ 2.70		+ 1.38	+ 1.47		+ 6.19	+ 2.30		- 0.37	- 0.17		- 0.81	- 0.06	
15	Total precipitation received as amounts ≥90th p	+ 0.71	+ 0.80		+ 3.42	+ 2.71		+ 1.45	+ 1.78		+ 5.12	+ 2.31		+ 0.40	0.05		+ 2.75	+ 0.67	
16	Total precipitation received as amounts ≥95th p	0.00	+ 1.30		+ 2.37	+ 2.59		+ 0.28	+ 1.39		+ 2.51	+ 1.67		- 0.85	- 0.70		0.00	+ 0.06	
17	Total precipitation received as amounts ≥99th p	0.00	- 0.41		0.00	+ 1.68		0.00	+ 1.29		0.00	+ 1.27		0.00	- 0.66		0.00	- 0.33	

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, ***Wine red ≤ 0.01, Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1****.*
Years for which data are missing: 1990, 1992, 2008

Appendix 4C.9. Dehradun, Western Himalaya (various multi-decadal periods): June-September

S. No.	Index	Trend for **June-September**																	
		1901-1950 (n=50)			1951-2000 (n=48)			1951-2013 (n=59)			1951-1980 (n=30)			1981-2013 (n=29)			2001-2013 (n=11)		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	p
1	Seasonal precipitation	+ 9.18	+ 1.71		- 1.74	- 0.61		- 1.23	- 0.46		+ 2.60	+ 0.25		+ 17.32	+ 2.04		+ 75.35	+ 1.71	
2	Wet days	+ 0.27	+ 2.24		+ 0.07	+ 0.74		+ 0.08	+ 1.10		+ 0.27	+ 1.27		+ 0.28	+ 1.75		+ 2.50	+ 0.23	
3	Mean daily precipitation intensity	+ 0.05	+ 1.00		- 0.06	- 1.86		- 0.06	- 1.92		- 0.09	- 1.11		+ 0.10	+ 1.07		+ 0.78	+ 1.87	
4	Maximum one-day precipitation	+ 0.04	+ 0.09		- 0.03	- 0.04		- 0.24	- 0.64		- 0.13	- 0.04		+ 0.46	+ 0.77		+ 2.64	+ 0.78	
5	Maximum three-day precipitation	+ 1.18	+ 1.59		- 1.34	- 1.64		- 0.85	- 1.57		- 1.27	- 0.50		+ 1.89	+ 1.56		+ 12.60	+ 3.11	
6	Maximum five-day precipitation	+ 2.30	+ 1.87		- 1.16	- 1.34		- 0.63	- 1.03		- 0.17	- 0.11		+ 2.36	+ 1.44		+ 24.13	+ 2.96	
7	Maximum wet spell length	+ 0.12	+ 2.03		+ 0.06	+ 1.22		+ 0.06	+ 1.48		0.00	+ 0.50		+ 0.08	+ 0.64		+ 0.29	+ 1.13	
8	Mean wet spell length	+ 0.02	+ 2.51		- 0.01	- 0.67		+ 0.00	+ 0.21		+ 0.02	+ 0.98		+ 0.04	+ 2.44		+ 0.05	+ 0.62	
9	Precipitation during longest wet spell	+ 5.26	+ 2.38		+ 0.37	+ 0.13		+ 0.36	+ 0.25		- 0.25	0.00		+ 3.95	+ 1.11		+ 25.43	+ 1.71	
10	Days with precipitation ≥80th p	+ 0.12	+ 2.23		- 0.05	- 1.06		- 0.04	- 1.01		- 0.07	- 0.74		+ 0.25	+ 2.21		+ 1.00	+ 1.57	
11	Days with precipitation ≥90th p	+ 0.09	+ 1.71		- 0.03	- 0.88		0.00	- 0.76		0.00	- 0.07		+ 0.19	+ 2.38		+ 0.56	+ 1.42	
12	Days with precipitation ≥95th p	+ 0.03	+ 1.02		0.00	+ 0.39		0.00	+ 0.35		0.00	+ 0.65		+ 0.09	+ 1.59		+ 0.33	+ 1.02	
13	Days with precipitation ≥99th p	0.00	+ 0.34		0.00	- 0.79		0.00	- 1.26		0.00	- 0.33		0.00	+ 0.54		0.00	+ 1.18	
14	Total precipitation received as amounts ≥80th p	+ 8.29	+ 1.96		- 3.04	- 0.74		- 2.50	- 0.77		- 1.81	- 0.11		+ 18.70	+ 1.78		+ 83.32	+ 1.71	
15	Total precipitation received as amounts ≥90th p	+ 6.88	+ 1.62		- 1.55	- 0.40		- 1.31	- 0.47		+ 2.06	+ 0.32		+ 16.47	+ 1.86		+ 61.80	+ 1.71	
16	Total precipitation received as amounts ≥95th p	+ 3.87	+ 1.00		+ 1.23	+ 0.40		+ 0.64	+ 0.27		+ 4.14	+ 0.46		+ 11.55	+ 1.59		+ 50.63	+ 1.40	
17	Total precipitation received as amounts ≥99th p	0.00	+ 0.50		0.00	- 0.47		0.00	- 1.00		0.00	- 0.11		0.00	+ 0.84		+ 17.34	+ 1.31	

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, ***Wine red ≤ 0.01, Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1****.*
Years for which data are missing: 1990, 1992, 2008, 2010

Appendix 4D: Winter Precipitation: Summaries of Trends

Appendix 4D.1. Darjeeling and Gangtok, Eastern Himalaya

S. No.	Index	Trend											
		Darjeeling 1901-1996*			Darjeeling 1901-1950*			Darjeeling 1951-1996*			Gangtok 1985-2014		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	P	Q	Z	P	Q	Z	P
1	Precipitation in January	+0.04	+1.28	n=88	+0.01	+0.39	n=49	0.00	-0.11	n=39	-0.57	-1.66	n=30
2	Mean daily precipitation intensity in January	+0.01	+1.28	n=88	0.00	+0.09	n=49	0.00	+0.12	n=39	-0.11	-1.36	n=30
3	Precipitation in February	-0.19	-2.73	n=87	+0.16	+0.62	n=49	0.00	+0.33	n=38	-1.57	-1.71	n=30
4	Mean daily precipitation intensity in February	-0.04	-2.51	n=87	+0.01	+0.27	n=49	0.03	+1.02	n=38	-0.06	-0.46	n=30
5	Precipitation in March	-0.19	-1.34	n=89	+0.02	+0.01	n=49	-0.82	-2.26	n=40	-0.17	-0.12	n=30
6	Mean daily precipitation intensity in March	-0.02	-1.09	n=89	-0.03	-0.53	n=49	-0.13	-1.83	n=40	0.00	+0.02	n=30
7	Precipitation in April	-0.24	-1.17	n=86	+1.40	+2.38	n=48	-0.45	-0.85	n=38	+4.89	+1.59	n=30
8	Mean daily precipitation intensity in April	-0.01	-0.84	n=86	+0.07	+1.96	n=48	-0.05	-0.98	n=38	+0.12	+1.03	n=30
9	Precipitation in December	0.00	-0.62	n=83	0.00	+0.39	n=49	0.00	-0.34	n=34	-0.50	-1.71	n=30
10	Mean daily precipitation intensity in December	0.00	-0.06	n=83	0.00	+0.76	n=49	0.00	+0.15	n=34	-0.11	-1.55	n=30

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, ***Wine red ≤ 0.01, Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1****.*
* Years for which data are missing (Darjeeling only): 1908 (D), 1909 (J, F, M, A), 1933 (A), 1953 (D), 1973 (D), 1975 (D), 1976 (D), 1977 (J, F, M), 1979 (J, F, M, A), 1980 (F, A), 1981 (D), 1982 and 1983 (J, F, M, A, D), 1984 (D), 1985 (J, F, M, A), 1986 (D), 1987 (J, F, M, A, D), 1989 (D), 1990 (D), 1991 (J), 1996 (F, A)

Appendix 4D.2. Gangtok, Eastern Himalaya (1985-2014): April, October

S. No.	Index	Trend					
		April (n=30)			October (n=30)		
		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p
1	Monthly precipitation	+4.89	+1.59		-1.08	-0.29	
2	Wet days	+0.14	+1.47		-0.04	-0.54	
3	Mean daily precipitation intensity	+0.12	+1.03		-0.02	-0.11	
4	Maximum one-day precipitation	+0.24	+0.55		+0.04	+0.05	
5	Maximum three-day precipitation	+0.80	+0.82		+0.47	+0.55	
6	Maximum five-day precipitation	+0.46	+0.49		-2.22	-1.53	
7	Maximum wet spell length	+0.07	+0.92		0.00	-0.75	
8	Mean wet spell length	0.00	0.00		+0.02	+0.70	
9	Precipitation during longest wet spell	+1.74	+0.68		-1.09	-0.96	
10	Days with precipitation ≥80th p	+0.12	+1.96		0.00	-0.45	
11	Days with precipitation ≥90th p	+0.08	+1.83		0.00	+0.07	
12	Days with precipitation ≥95th p	0.00	+1.32		0.00	+0.30	
13	Days with precipitation ≥99th p	0.00	+0.23		0.00	+0.02	
14	Total precipitation received as amounts ≥80th p	+4.44	+1.50		-0.89	-0.32	
15	Total precipitation received as amounts ≥90th p	+3.47	+1.27		-0.42	-0.16	
16	Total precipitation received as amounts ≥95th p	+1.71	+1.12		0.00	+0.09	
17	Total precipitation received as amounts ≥99th p	0.00	+0.30		0.00	-0.07	

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, Wine red ≤ 0.01, ***Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1.***

Appendix 4D.3. Dehradun, Western Himalaya

S. No.	Index	Trend														
		1901-2014 (n=114)			1901-1950 (n=50)			1951-2014 (n=64)			1951-1980 (n=30)			1981-2014 (n=34)		
		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T		SE	M-K T	
		Q	Z	p	Q	Z	p	Q	Z	p	Q	Z	P	Q	Z	P
1	Precipitation in January	-0.10	-1.03		+0.03	+0.20		-0.48	-1.62		-2.00	-2.07		+0.04	+0.16	
2	Mean daily precipitation intensity in January	+0.00	0.00		+0.01	+0.07		-0.05	-0.96		-0.29	-2.39		+0.00	+0.01	
3	Precipitation in February	0.00	+0.03		+0.22	+0.45		+0.52	+1.60		+0.73	+1.00		+0.68	+0.70	
4	Mean daily precipitation intensity in February	-0.01	-0.39		+0.11	+1.49		+0.07	+1.17		+0.10	+0.62		+0.24	+1.66	
5	Precipitation in March	+0.07	+0.82		+0.08	+0.36		-0.14	-0.79		-0.54	-0.61		-0.69	-1.05	
6	Mean daily precipitation intensity in March	+0.01	+0.33		+0.02	+0.44		-0.05	-1.15		-0.03	-0.29		-0.12	-1.02	
7	Precipitation in April	+0.11	+2.42		+0.03	+0.43		+0.29	+2.60		+0.15	+0.71		-0.16	-0.56	
8	Mean daily precipitation intensity in April	+0.03	+2.33		+0.00	+0.07		+0.06	+2.04		+0.02	+0.36		-0.01	-0.18	
9	Precipitation in December	0.00	-0.34	n=110	0.00	0.00		0.00	-0.39	n=60	+0.13	+0.70		-0.40	-1.88	n=30
10	Mean daily precipitation intensity in December	0.00	-0.65	n=110	0.00	-0.03		-0.01	-0.91	n=60	+0.00	+0.11		-0.29	-2.38	n=30

Abbreviations and symbols: SE: Theil-Sen Estimator, Q: Slope Estimate, M-K T: Mann-Kendall Test, Z: Test Statistic Z, p: Asymptotic Significance
Colours denote significance levels: Purple ≤ 0.001, ***Wine red ≤ 0.01, Orange ≤ 0.05, Yellow ≤ 0.1, Grey: >0.1***.

* Years in which data are missing for the month of December: 1992, 1994, 2012, 2014